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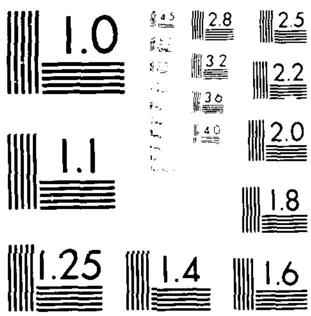

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A METHODOLOGY FOR DETERMINING THE

INTENT OF A LIMITED NUCLEAR ATTACK

THESIS

Robert L. Bivins
Captain, USAF

AFIT/GST/ENS/87J-2

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The purpose of this study was to develop a methodology for determining the intent of a limited nuclear attack. An investigation of possible methodologies for determining intent lead to research in Bayesian analysis. It was thought that the answer to intent could be found by taking prior beliefs of the decision maker and then using Bayes' Theorem to update those beliefs with ground-based radar information obtained over time.

Unfortunately the use of Bayesian analysis as proposed here in this research did not prove to be robust when the radar information is inaccurate. The desired answer was the proportion of the attack which was against each class of targets, city/industrial, "other" military, strategic military, and critical command and control or communications. The results at the current radar accuracies yield an inaccurate estimate of the proportion of the attack which is against each of the target classes. When the accuracy of the radar is improved, the proposed methodology does converge to the correct proportions.

The reason for the inability of the proposed methodology to perform under the inaccurate radar parameters is that the methodology ignores too many of the complicating issues in determining intent. Also, the accuracy of the predicted impact points improve as the warhead gets closer to impact but the proposed methodology does not account for this change in the accuracy of the impact points. Some refinements to the proposed methodology are offered as an attempt to reduce the inaccuracy in the estimates of the proportions. Essentially these refinements involve generating weighting functions to be used in the Bayesian analysis which modify the amount that the prior probabilities are modified by the observed samples. When the estimated impact points are inaccurate and thus the confidence in the sample is low, then the weighting function will be close to unity so that the priors are modified very little. When the predicted impact points are accurate, then the weighting function should allow the prior probabilities to be significantly modified.

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A METHODOLOGY FOR DETERMINING THE INTENT OF A LIMITED NUCLEAR ATTACK

THESIS

Presented to the Faculty of the School of Engineering of

the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Robert L. Bivins, B. S., M. S.

Captain, USAF

May 1987

Preface

This research effort began on February 26, 1986 when Lt. Col. Richard A. Lawhern from the Strategic Command and Control, Communications, and Intelligence branch at the Air Force Center for Studies and Analysis addressed the students at AFIT. He challenged the students to find the accuracy of the attack warning and characterization system needed to correctly determine the intent of a limited nuclear attack. His challenge launched my year and half quest for an answer and the completion of this effort. I never did find the answer to Col. Lawhern's question but I did find the strength in my family and myself.

Sharon, you truly are are amazing! How do you put up with me? I love you. Without you and the kids, Mike, Joe, and Storm, this effort would have been impossible and meaningless. I would like to thank my thesis advisor, Major Joe Litko who worked with me every step of the way. Without his help and intelligence, this research would have never been possible. I would also like to acknowledge the help of Mr. Larry Lillard who aided in the reprogramming and debugging of TSP, the trajectory simulation program. I would also like to thank my classmates who helped me endure this process through their own hardships and experiences.

Robert L. Bivins

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Abstract

The purpose of this study was to develop a methodology for determining the intent of a limited nuclear attack. An investigation of possible methodologies for determining intent lead to research in Bayesian analysis. It was thought that the answer to intent could be found by taking prior beliefs of the decision maker and then using Bayes' Theorem to update those beliefs with ground-based radar information obtained over time.

Unfortunately the use of Bayesian analysis as proposed here in this research did not prove to be robust when the radar information is inaccurate. The desired answer was the proportion of the attack which was against each class of targets, city/industrial, "other" military, strategic military, and critical command and control or communications. The results at the current radar accuracies yield an inaccurate estimate of the proportion of the attack which is against each of the target classes. When the accuracy of the radar is improved, the proposed methodology does converge to the correct proportions.

The reason for the inability of the proposed methodology to perform under the inaccurate radar parameters is that the methodology ignores too many of the complicating issues in determining intent. Also, the accuracy of the predicted impact points improve as the warhead gets closer to impact but the proposed methodology does not account for this change in the accuracy of the impact points. Some refinements to the proposed methodology are offered as an attempt to reduce the inaccuracy in the estimates of the proportions. Essentially these refinements involve generating weighting functions to be used in the Bayesian analysis which modify the amount that the prior probabilities are modified by the observed samples. When the estimated impact points are inaccurate and thus the confidence in the sample is low, then the weighting function will be close to unity so that the priors are modified very little. When the predicted impact points are accurate, then the weighting function should allow the prior probabilities to be significantly modified.

A METHODOLOGY FOR
DETERMINING THE INTENT
OF A LIMITED NUCLEAR ATTACK

I. Introduction

Motivation

> The ability of the U.S. early warning system to keep pace with the multitude of strategic threats the Soviets can now throw against it justifies characterization of U.S. strategic deterrence as a tetrad, *with warning and attack characterization equal in potency* to land- and sea-based missiles and manned bombers in discouraging a Soviet first strike. (emphasis added)
>
> General Hartinger, CINC NORAD
> Colorado Springs, Colorado 1980

U.S. military commanders are just now beginning to understand the importance of attack characterization and intent determination. In support of this interest, the Air Force and the Department for Advanced Research Projects Agency (DARPA) are currently conducting research in the area of determining intent in the presence of uncertainty [34]. Because of senior Air Force leadership interest in the Rapid Application of Air Power program, "pattern recognition" which attempts to resolve uncertainty ("to find pattern in apparent chaos" [39: 3]) has become a key issue. It is believed that recognizing what the enemy's objectives are affords the U.S. the greatest opportunity to defeat the enemy. Knowing the enemy's objectives requires application of pattern recognition techniques to sort through all of the possible objectives to determine the enemy's true intent [36]. How do we "pattern match" actions to intent? The determination of intent is never easy. But it is especially difficult when a high degree of uncertainty exists such as when the enemy's actions suggest more than one plausible objective.

This high degree of uncertainty would exist during a limited nuclear attack upon the United States if the predicted impact points of the incoming reentry vehicles were near several different types of targets. In that situation, U.S. military advisors to the President would be uncertain as to the exact nature of the attack and therefore would find it difficult to recommend the appropriate response action to the National Command Authority (NCA). The U.S. would find in necessary to pattern match the characterization of the attack to the Soviet intent. But how could the U.S. do this? Using today's methods, they would not be able to determine from the attack characterization if the Soviets intended to perform a surgical strike against selected strategic targets, a show of force and resolve by attacking urban or industrial targets, or a "decapitation" of U.S. military command and control, or communications. Bruce Blair of The Brookings Institution in *Strategic Command and Control* had this observation about Soviet intentions which are always laden with uncertainty. Soviet actions combined with the uneasiness that would be felt if the attack was against U.S. command and control, or communications (C^3) would present U.S. commanders with a very difficult problem.

> Testifying in 1963, Admiral Galantin concluded that Soviet attack on any one of the shore-based VLF stations used to broadcast messages to missile submarines 'would probably mean an all-out war.'
>
> Galantin's remark also reflects a subjective assessment of Soviet intentions and motives. There is widespread belief that attack, however small, on U.S. C^3I elements would presage a large-scale missile barrage against U.S. targets. But while intentions are potentially a key distinguishing feature of levels of conflict, actual motives are often ambiguous. A range of different but equally plausible motives could be inferred from a limited attack against the command structure. For instance, an attack on U.S. reconnaissance satellites might be designed to impair the ability of the United States to assign targets to its strategic forces. But such an attack might instead be designed to send a political signal or demonstrate resolve while minimizing the scale of provocation. Antisatellite attack may be like some limited U.S. nuclear options in that demonstrating resolve is the primary objective. [5: 221]

It should be obvious that due to the importance of attack warning and assessment in deciding Soviet intent, the system needs to be very reliable and very accurate.

Current Situation. Unfortunately the United States' nuclear attack assessment and warning system does not currently perform to the level desired by the National Command Authority with respect to attack characterization (5: 225-226; 10). If the Soviets launched a large-scale nuclear attack (hundreds to thousands of warheads), the United States would have a reasonably good "picture" of how many warheads were incoming because the system is specifically designed for the detection of a large-scale attack [30]. Determining the enemy intent during a large-scale attack would be relatively easy. Because all types of targets would receive large amounts of damage, the intent of the enemy would clearly be to inflict as much damage on the United States as possible. Under this scenario there would be a limited number of response options because of the clarity of the Soviet intent and the need to make a drastic attempt to counter the attack. However, under a limited attack scenario (less than a hundred warheads) the ability of the attack assessment system to "correctly" characterize the attack is non-existent. The current system lacks the ability to properly discriminate the intended target from among all the possible targets in the area when the predicted impact point is such that several targets would be damaged by the nuclear effects of the warhead [22: 40]. A description of how the attack assessment system operates from launch to impact illustrates this lack of characterization capability.

Attack Assessment Scenario. Consider the situation where the launch of an Intercontinental Ballistic Missile has just occurred (See Figure 1.1). First the attack assessment system detects the launch with Defense Support Program (DSP) satellites approximately one minute after booster ignition [5: 223; 22: 38]. At this point a determination of heading is made but it is very inaccurate. After three to four minutes of powered flight, the satellites lose track of the missiles.

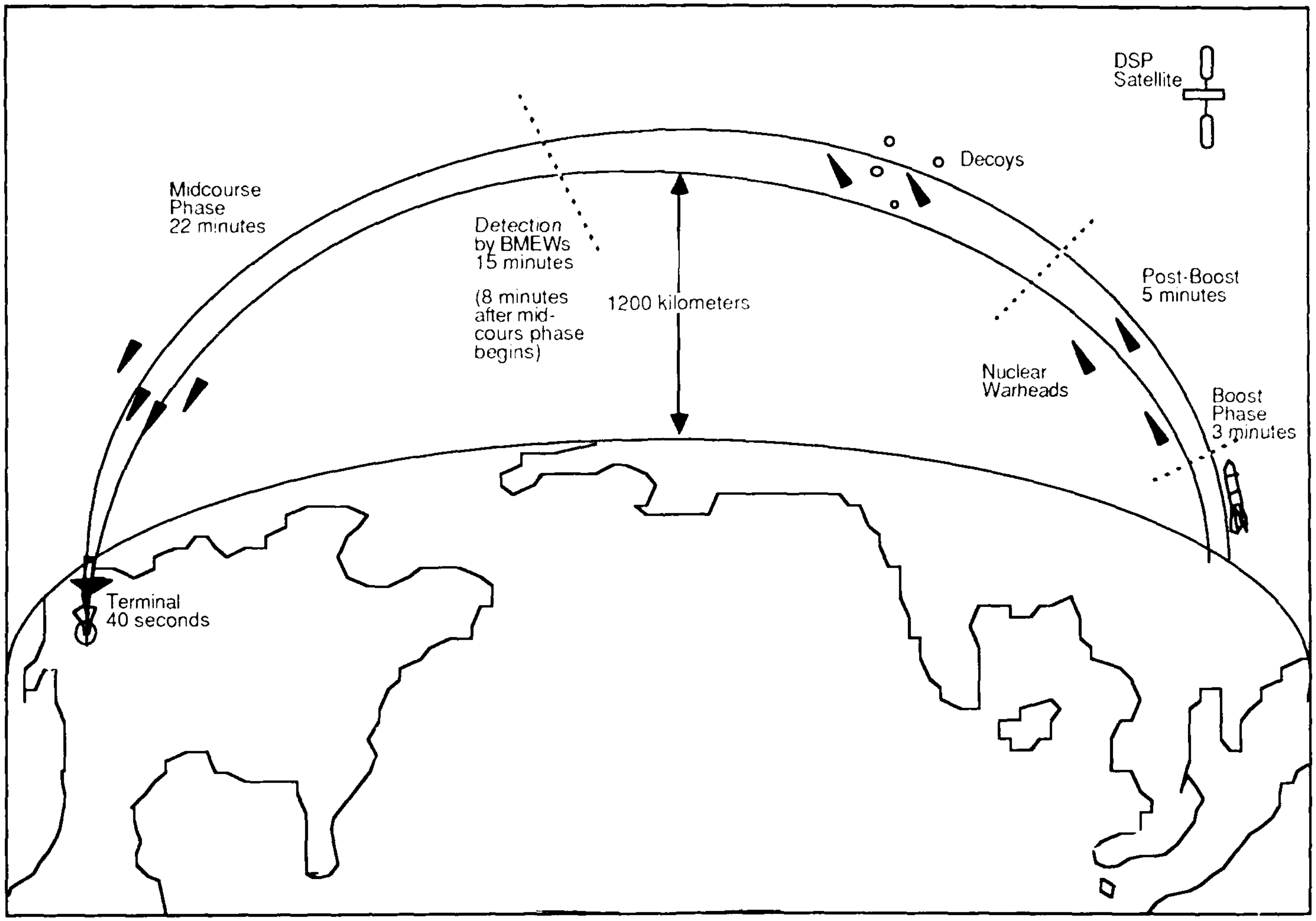

Figure 1.1 Simulated Launch
(Adapted from [41])

Approximately ten minutes later when the warheads and decoys have been dispersed from the reentry vehicle bus, the warheads will be detected by the Ballistic Missile Early Warning System (BMEWS). This detection by BMEWS will occur about 15 minutes prior to warhead detonation. At this point the attack is confirmed and information about the type of attack underway is transmitted to the North American Air Defense Command (NORAD) headquarters and other high-level military command and control centers (See Figure 1.2) [5: 223; 22: 38].

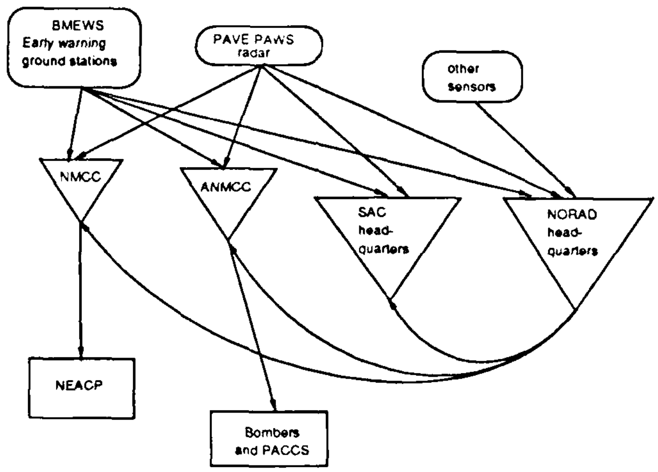

Figure 1.2 Information Flow
(Adapted from [5: 251])

This attack characterization data is reasonably accurate but as will be shown it is too limited to ascertain intent when the predicted impact points occur in areas that are "target rich environments" [30]. When the radar detects the incoming reentry vehicle an impact point is predicted. The computers at NORAD will run an algorithm to determine the targets "at risk" from each reentry vehicle [30; 22: 38]. The computer's algorithm takes each impact point and compares it against its stored target data base. The targets in the stored target base are classified into five classes:

Class 1, urban/industrial centers
Class 2, missile fields
Class 3, bomber/tanker fields
Class 4, U.S. command and control centers
Class 5, Washington, D.C. [22: 45]

A "target zone" is calculated for each target in the data base. Information about these target zones are classified but essentially they are the area surrounding a target where if the warhead detonates in that area, then the target will receive enough damage to be considered destroyed [30]. The target zones are different sizes for each of the five classes of targets because each type of target is hardened to different levels of damage from nuclear effects. The computer algorithm begins by searching the target base for any target zones which contain the predicted impact point as illustrated in Figure 1.3. Once a target zone is found, the class of the target is determined (Class 1 through 5) and that target class along with other critical information is displayed on the Missile Warning Officer's display panel in the Tactical Operations Room of NORAD inside Cheyenne Mountain.

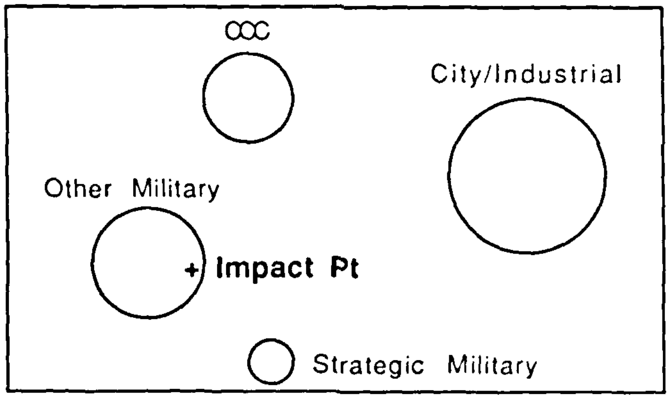

Figure 1.3 Target Zones

This panel shown in Figure 1.4 displays information about each incoming warhead. This display is similar to the one inside NORAD's Tactical Operations Room but it is not the actual display. To the far left-hand side of the screen each reentry vehicle is identified with a number.

Select Attack	Tgt Char	Impact Point	Track Phase	Impact Time	Launch Point	Object Id	Target Class Summary	Raid Size	Impact times
1	145	32.2534 121.3457	TG-1	655 sec	50.3418 53.4520	21	1 - 0 2 - 1 3 - 0 4 - 0 5 - 0	ICBM - 1	None
2	32	31.4321 120.5432	TG-2	715 sec	50.3418 53.4520	22	1 - 1 2 - 1 3 - 0 4 - 0 5 - 0	ICBM - 2	None

Earliest Imp 655 sec
Next Imp 715 sec

Figure 1.4 Missile Warning Display Panel
(Simulated, not an actual warning panel)

On each line across from the number of the reentry vehicle the following information is displayed:

- **Selected target for attack characterization** — A code number corresponding to the specific city, military facility, or command and control center which is being attacked by the particular reentry vehicle.

- **Impact point** — Specific latitude and longitude coordinates of the target being attacked. These coordinates are updated as the reentry vehicles get closer to impact and the radar data becomes more exact.

- **Track phase** — Displays either TG-1 or TG-2 which is a code for the accuracy of the data for the particular target shown as under attack. Accuracy of the radar in the TG-2 phase of tracking is reported to be within several thousand meters and is *generally* considered to be reliable enough to determine what specific target is being attacked.

- **Impact time** — Time that the reentry vehicles are predicted to impact.

- **Launch point** — The latitude and longitude of the missile's launch point. This information is reported to be very accurate and is used to determine what type of weapon was launched. This information can also be used by U.S. commanders to update the targeting of the Soviet Union for retaliation.

- **Object identification** — The computer catalog of the reentry vehicle.
- **Target class summary** — Total number of warheads airborne toward each class of targets. As if keeping score, each target class (1 through 5) is displayed with the total number of weapons classified as intended for that class of targets.
- **Raid size** — Total number of warheads headed for the U.S. and a breakdown of the number of ICBMs and Submarine Launched Ballistic Missiles (SLBMs).
- **Impact times** — The impact time of the first warhead to detonate over Washington, D.C. is specially reported. The "next impact" time is also reported.

The screen also displays the time of the earliest impact over U.S. soil and the next impact time after the first impact. A large map of the U.S. and Canada is also displayed with the tracks of the reentry vehicles being shown as they move down the map from over the North pole. All of this information is provided starting from about 15 minutes prior to first impact [22: 40,44-45]. Because of the time required to send an execution message to strategic forces and the time required for those forces to respond, only data down to 6 minutes prior to first impact is relevant in this study. Figure 1.5 shows the time available for a U.S. response throughout the time sequence of a hypothetical Soviet attack.

The commander-in-chief (CINC) NORAD would use the attack warning and characterization data obtained during the 9 minutes (15 down to 6) prior to first impact to advise the President and the National Command Authority (NCA) on the type of attack that was occurring. This advice to the NCA would include an assessment of the system's confidence and CINC NORAD's confidence in the warning and characterization data [22: 45].

CINC NORAD would take all the information he has received about sites and system confidence along with his personal assessment based on the current world situation and other factors to generate the CINC NORAD assessment. This assessment would be reported as a "high," "medium," or "low" confidence and if possible would be verbally reported to the President and the NCA. The CINC NORAD and system confidence

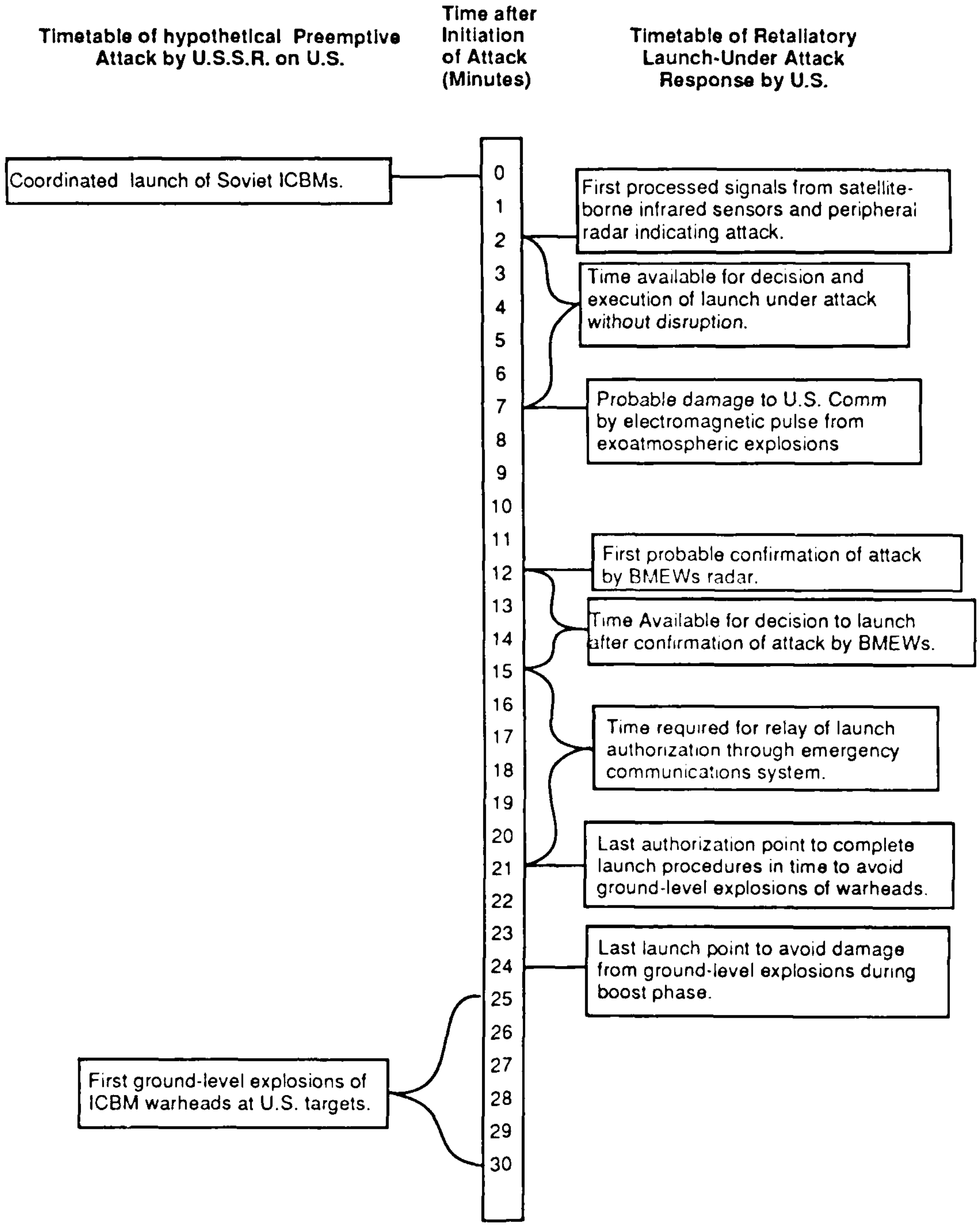

Figure 1.5 Hypothetical Nuclear Attack Time Line
(Compiled from [40: 39])

assessments do **not** have to agree. The CINC NORAD assessment is his judgement of whether an attack is underway against the North American continent [30]. CINC NORAD would describe to the President what type of attack was occurring based on the **target class summary** information. His recommended retaliatory measure would be heavily influenced by the size of the attack (**raid size**) and the target class "under attack" determined from **target class summary**. If a large proportion of the attacking warheads were determined to be targeted against U.S. command and control, or communications (C^3) centers, then the CINC NORAD recommendation might be rapid retaliation before the "decapitating" warheads could impact their targets. Because an attack against C^3 centers would "force" a rapid and possibly unrestricted response it is vital to national security that the attack warning and assessment system perform as accurately as possible.

Deficiency in Attack Characterization. A major problem currently exists with the method for determining the target class under attack. It is the supposition of this thesis effort that the algorithm which is used to generate the **selected target for attack characterization** contains a serious flaw in logic. The computer algorithm currently searches the target base first starting with all the major cities in the United States. There are approximately a thousand cities in the United States with the population and industry levels appropriate for considering them as possible targets [9: 103]. If the predicted impact point of the reentry vehicle is within a target zone of a city, then the characterization system will record that city's specific code under the **selected target for attack characterization** category for the reentry vehicle. If another city's target zone also contains the predicted impact point then its code will also be displayed under the **selected target for attack characterization** category on the missile warning officer's display panel.

After all the city target zones have been checked against the predicted impact point, the computer algorithm then starts searching for any other target zones which might contain the predicted impact point. If other target zones are found to contain the predicted impact point, then their target codes are listed in the **selected target for attack characterization** category in addition to all other previous target codes. It is highly possible and does occur during exercises that a particular reentry vehicle may have more than one city code assigned against it and in fact may have targets from more than one target class assigned to it. These multiple assignments are then *all* reported under the **target class summary** category on the display inside NORAD's Tactical Operations Room. This method of assessing attack characterization basically assumes an equal weighting for each target whose target zone contains the predicted impact point.

This equal weighting of all targets is potentially very misleading. It could happen that in an area of high target density where many targets of several different target classes are located the true intent of the attack could be obscured. Consider for example the situation depicted in Figure 1.6 where a warhead is predicted to land in a heavily populated and industrialized area surrounding a U.S. military command and control, or communications center such as the satellite control facility at Sunnyvale California.

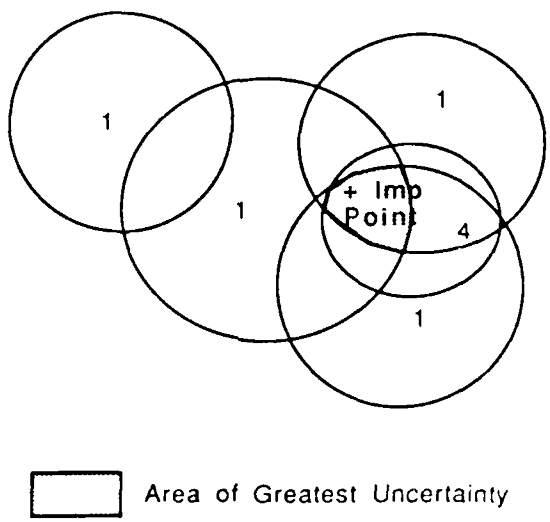

Figure 1.6 Predicted Impact Point in Target Rich Environment

A warhead impacting in this area could be aimed at the command and control, or communications target but due to the random nature of the reentry vehicle and the inaccuracy of the radar systems predicting impact points the **selected target for attack characterization** information for this warhead would be misleading. The current algorithm would show the warhead as attacking three city/industrial targets (Class 1) and one C^3 target (Class 4). Repeated over the entire limited attack, the **target class summary** information could become overly inflated with Class 1 targets as the target class under attack. This situation could result in CINC NORAD incorrectly "reading" the Soviet intent and recommending an inappropriate retaliatory response to the National Command Authority. It is the inability of the attack assessment and characterization system to correctly determine the Soviet intent in a limited nuclear attack when a large amount of uncertainty exist that has prompted this research effort.

> ***The current system simply lacks the intent determination feature which would be critically needed during a limited nuclear attack.***

Purpose of Research. In the winter of 1986, Lt. Col. Richard Lawhern from the Air Force Center for Studies and Analysis (AFCSA) identified the current attack characterization deficiency to students at the Air Force Institute of Technology. He stated that he and fellow analysts in the Command, Control, and Reconnaissance division at AFCSA were interested in learning more about attack characterization "because the current system lies." [25] The specific question he posed at the time was the following:

> Given an area of the United States that contains critical command and control, or communications centers and other targets such as an Air Force base or an industrial center, what are the accuracies of the attack assessment and characterization system that would be necessary to 'correctly' predict which target in the area is the intended target of the detected reentry vehicle? [25]

Further conversations with Lt. Col. Lawhern lead the research away from further sensitivity analysis of the radar and target sorting algorithms [26] to more analysis in the area of "target deconfliction." [32]

Target deconfliction is the resolution of the uncertainty which exists when more than one target and target class are identified as being at risk from a particular reentry vehicle. A true understanding of the probabilities involved which infer intent is required to resolve the uncertainty contained in this problem. Intent can be inferred by taking new information about a particular aspect or "state of nature" and combining the new information with knowledge or assumptions (prior probabilities) about the state of nature before information is received [20: 616, 619-620]. A majority of the thesis effort was spent in developing a methodology for doing target deconfliction so that the enemy's intent could be determined.

According to Lt. Col. Lawhern, an expected benefit from the research is that "the proposed methodology could be used by the U.S. Space Command as a basis for validating their attack assessment system. It could also have an impact on the procurement of attack assessment systems in the future." [26]

Desired Outcome. There are several desired outcomes or expectations of the thesis effort. First that a methodology would be found or developed which could take the received sensor data of the attack warning and assessment system and "correctly" characterize the attack. This characterization involves finding the proportion of the attack which is intended for each of the five classes of targets (city/industrial, other military, strategic military, C^3, and Washington, D.C.). Second, once the attack has been characterized, that an estimate could be made of the confidence interval associated with the proportions of each target class under attack. This confidence interval of proportions could help CINC NORAD in formulating his assessment of the attack. Third, that the level of sensor accuracy could be found which would improve the attack characterization to the point that CINC NORAD would be 98% sure what type of attack was taking place on the

North American continent. It is recognized that the research may show that no amount of improvement in sensor accuracy is capable of delivering this confidence level. Other levels of confidence such as 75% and 90% will also be examined. Fourth, that a clearer understanding of the attack assessment system could be gained by investigating all of the factors which affect target characterization. This investigation will be accomplished by performing sensitivity analysis on the major factors in the attack assessment system. These major factors are the size of the attack, the timing of the attack, the yield of the warheads, the accuracy of the warheads, the distribution of the targets, and the actual nature of the attack. Finally, that through this research a better understanding of how intent is determined when there is a large amount of uncertainty involved.

Additional Uses of Research. Since this research deals heavily with determining intent, there are several areas which could benefit from the results of this study. The Strategic Defense Initiative (SDI) is one of these areas. It has been acknowledged that a Ballistic Missile Defense system might need some way of accurately determining which of several possible targets is the intended target of an attacking reentry vehicle. This capability would be necessary when some particular subset of targets was to be protected and the Ballistic Missile Defense system did not have the resources to protect all possible targets.

> The most serious threat to tracking is a maneuvering RV that could make a strike far from its predicted impact point. This tactic is effective if the defense is trying to save some subset of the targets being attacked and wants to intercept only RVs heading for these targets. [9: 60]

The SDI area is rich with opportunities for using the results of this research. Another general area which might be aided by this research is "pattern recognition."

The methodology that will be used to determine intent based on the sensor data is similar to those techniques currently used in pattern recognition. Bayes' rule is used to determine the cost of misclassification and consideration of misclassification is a big part of pattern recognition [35: 15]. As will be shown later, Bayes' rule is employed as a large part of the methodology for determining the intent of a limited nuclear attack given some sensor data over time.

Problem Statement

Currently there is no methodology for determining the Soviet intent during a limited nuclear attack when the intended targets are collateral with other possible targets. The development and acceptance of a methodology to determine the Soviet intent in a limited nuclear attack would resolve uncertainty and increase the confidence of NORAD's attack characterization.

Research Objective

Develop a methodology which can be used to determine intent in a limited nuclear attack given attack assessment and characterization data from missile warning sensors. Use the methodology to investigate the sensors' accuracy to determine if a threshold exists which would enable 75, 90, and 98% of the warheads to be correctly classifed during the attack characterization.

Research Sub-objectives

In support of the research objective the following sub-objectives will be investigated.

a. Develop a Measure of Effectiveness (MOE) which can be used to evaluate prospective methodologies for determining the intent of a limited nuclear attack.

b. Find the sensor accuracy needed to enable the missile warning system to provide attack characterization at the 75, 90, and 98% correctly-classified levels.

c. Analyze how missile accuracy (circular error probable, CEP) affects attack characterization.

d. Given the most accurate missile warning system possible, determine the longest time before first warhead detonation at which the attack characterization could be determined at the 98% correctly-classified level.

Limitation of Scope

In order to accomplish the stated objective and subsidiary objectives, the scope of the problem needed to be appropriately limited. First, the research was restricted to the unclassified level. Due to the amount of sensitivity analysis conducted it is felt that the results will be easily transferable to the actual classified data bases. The geographical area of interest was limited to the state of California. This state was chosen because of its large number of targets in four major target classes (city/industrial, other military, strategic military, and C^3). The research only considered limited nuclear attacks because of the senselessness of trying to characterize an attack that consists of several hundred warheads. With hundreds of warheads the target class of interest, C^3, would experience enough damage that the ability of the U.S. to respond to the attack would be severely reduced. Only ground targets were considered in the target data base. It is felt that if space assets are attacked the intent of the Soviets is clearly to disrupt U.S. military command and control, and communications, and the U.S. should respond accordingly.

Definition of Terms

There are several terms which require some elaboration. Most of these terms will be used throughout the thesis and their definition here serves to clarify their usage and make visible the inherent assumptions.

Attack Assessment — The information gained concerning imminent or actual attack against the United States involving nuclear weapons. This information may come from Ballistic Missile Early Warning System (BMEWS) radar sites or space-based infrared sensors. These systems combined are capable of assessing the number of launches, launch sites, time to impact, impact points, and other relevant attack data [5: 223-226].

CEP — Circular error probable is the area in which on the average, half the warheads will land. It is the radius of that area usually measured in meters and is the accepted measure of ICBM accuracy.

Critical Command and Control, and Communications — In the United States there are about a hundred command and control, and communications facilities that are considered vital to either attack assessment and or control of nuclear retaliatory forces. These facilities include such things as radar sites, communication relay stations, and satellite control facilities. They also include command posts, the National Command Authority, and alternate command facilities [11: 30]. These facilities are necessary to employ nuclear weapons. Therefore, these facilities are considered "critical" command and control, and communications facilities.

Limited Nuclear Attack — Because an attack consisting of hundreds of warheads would cause such a high level of damage, debris, and electromagnetic pulse throughout the United States that critical parts of the U.S. communications system would not operate effectively, a limited nuclear attack will be defined as an attack consisting of less than a hundred nuclear warheads [42: 1310]. Since only a portion of the United States will be considered in the research the number of warheads to represent a limited attack in the area of interest will be approximately 10% of the total number of targets in a particular area.

Overview

This chapter has contained the introductory information. Chapter II will contain background material. The background material will include a review of the literature concerning the problem area and information collected from discussions with missile warning experts. Chapter III will contain a discussion of the simulation and mathematical models used to generate the data for the analysis. Chapter IV will contain a discussion of the methodology used to solve the problem. A brief explanation will be given concerning what other methodologies were investigated and why they were rejected. The theoretical foundation for using the adopted methodology will be presented. Finally the test conditions, hypotheses, and experimental design will be discussed. Chapter V contains the findings and analysis. The results of experimentation and an analysis of those results are thoroughly discussed with respect to the research objectives they answer. Finally some conclusions and recommendations are presented in chapter VI.

II. Background

Overview

This chapter will contain all the relevant background information collected about the attack characterization and intent determination problem. The majority of information was collected from two sources, a thorough literature review and discussions with missile warning experts. This information led directly to the discovery of what data had to be collected or generated to meet the research objectives.

Review of Literature

Lt. Col. Lawhern, a former deputy chief of the Command, Control, and Reconnaissance Division at Studies and Analysis and the inspiration for this research has commented that he knows of no previous research in the specific area of intent determination of a Soviet limited nuclear attack [25]. This statement was supported when an exhaustive search of the literature failed to expose any published studies in the area of intent determination in a nuclear attack scenario. However, during the literature review several studies were located which dealt with topics related to the research objective. These related topics were studies of attack warning sensors, damage expectancy and vulnerability studies, and pattern recognition. Each of these three areas of studies will be briefly reviewed in the following sections.

Attack Warning Sensors. Several Department of Defense studies have been sponsored in the area of nuclear detonation detection with regards to treaty verification and damage assessment. These studies are related to the research topic because they involve various components of the sensor system necessary to perform attack characterization.

These sensors perform warning functions day-to-day and then provide attack warning if a launch is detected. After launch detection, the U.S. would attempt to characterize the attack. From the character or nature of the attack (how many warheads are targeted against each class of targets), an attempt would be made to determine intent. This intent determination is the focus of this thesis. All of the previously mentioned actions occur before any warheads have detonated. Once detonations start occurring, the sensor warning system would perform damage or attack assessment. These assessment functions would be supported by both space-based satellites detecting detonations and ground-based seismic sensors. The research in this area was useful because of the information it provided about the various sensor systems and their capabilities.

The first study reviewed gave insight into the types of sensors which are currently deployed and planned for deployment for attack warning and assessment. The "Forward Based Systems" study, published in November 1973, conducted "a review and an assessment of feasible sensors within the electromagnetic spectrum operating from appropriate platforms." The research provided "a basis for determining forward based surveillance system requirements in support of ballistic missile defense." [12: 1]

A second study gave information concerning a submarine launched attack. The SLBM defense technology requirements study was published in November 1976. The study's emphasis was "to determine technology requirements to maximize SLBM defense warning time and provide accuracy threat assessment and to determine the parametric effects and interactions between reaction time and required SLBM defense...The contractor proposed several advanced satellite sensor concepts and advanced interceptor concepts which can defend against SLBM attacks." [12: 6] As a result of information gained from this study, it was decided to exclude an SLBM attack from the attack characterization model during the research. The reason for this exclusion is based on the limited time that would be available to make an intent determination. An SLBM can launch and detonate its warheads within 6 minutes at normal patrol range. Even immediate intent determination would not allow enough time for any credible response. The intent determination of an SLBM limited nuclear attack will be left for future research.

The last study reviewed in the area of attack assessment and warning sensors was the nuclear detonation detection system (NDS) utility study (trans-attack application). Completed in August of 1984, this study evaluated the "contribution of NDS to strike assessment." [13: 53] This study is interesting because it attempts to relate sensor capability to attack assessment. The study is related to the research because it attempts to answer one of the questions in the logical sequence of questions of can the U.S. determine **if** they are under attack (attack warning), **what** targets are being attacked (attack assessment or characterization), and **what** is the intent of the attack (intent determination). The next area of research discussed is the area of damage assessment and vulnerability studies.

Damage Expectancy and Target Vulnerability. This area of research is applicable to the thesis research objective because it concerns methods for estimating damage to a particular type of target. This information is necessary for the research effort because in order to ascertain intent in a high density target area the different levels of damage to each target in the area needs to be determined. This expected damage information could then be used to differentiate the intended target from among the different target classes using an appropriate methodology. As mentioned in chapter I, the relative sizes of the target zones for different target classes are not the same. This difference comes about because of the different levels of vulnerability each different class of targets would experience when subjected to the same level of nuclear effects. Some of the cited studies only address damage expectancy while some relate the expected damage to the survivability of the target.

The first study reviewed in this area is the "Effectiveness and Target Assessment" study published in December 1974. The objectives of this study were to:

1) "Assess the damage probability versus range for various targets as a function of weapon type, yield, and burst-altitude."
2) "For various attack-objectives and target complexes, summarize the desired warhead type, yield, CEP, and burst altitude."
3) "Determine major weapon-effect uncertainties (e.g., output, environment, target response) impacting the capability to attack, while producing minimal undesired damage." [13: 57]

This study validated the approach taken in the damage calculation model used to generate some of the data for the research. This model and its data will be discussed in Chapter III.

The next study reviewed was the "Evaluation of C^3 Degradation for JCS ELITE TROOPER Exercise" published April 1983. The objective of this study focused on the class of targets of most interest in this research, C^3. The objective of the research was to "evaluate the effects of damage to C^3 systems of the NCA resulting from the nuclear attack..." [13: 72] This study validated the concern over a decapitation attack.

Command and control, and communications is also the topic of the next study which was reviewed. A communications survivability study was published in April 1985. This study developed "a reference document of strategic command, control, communications and intelligence C^3 systems nuclear survivability issues to include the updating with the latest calculated nuclear effects on the vulnerability/hardness of each link and node of strategic connectivity networks." [13: 136] The study validated the parameters used in the damage calculation model for the C^3 targets.

One of the most interesting studies reviewed was the "Consequences of 'Limited' Nuclear Attacks on the United States study published in 1986. This study approached the consequences of nuclear war from an analysis of the civilian casualties which would result from various different strategies of attacks. The study was very useful in developing an appreciation for the various different levels of damage which would result from attacks which "intended" minimal collateral damage [11: 3-45]. It was also useful in determining some of the parameters that were used in the damage calculation model. Finally, the model provided information about the command and control, and communications targets which are in the geographical area of interest in the research.

The studies that have been reviewed here demonstrate the varied types of research occurring in the area of damage expectancy and target survivability. The information gained from these studies and other sources were critical to developing the models to generate the data for this study. The last group of studies which will be reviewed are those dealing with pattern recognition.

Pattern Recognition. No studies were found which directly related pattern recognition to using targets attacked to give estimates of target classes under attack. The studies which are reviewed deal either with attack assessment or pattern recognition in a general sense.

The first study reviewed in this area validated the idea that the Soviets might attempt a limited nuclear attack against a subset class of targets and that the U.S. correct determination of the "class under attack" could control escalation. The "Changing Balance" study of February 1983 had as its objective the examination of the "impact of nuclear force deployment and nuclear employment on escalation control." The approach the study used was to "broaden the range of scenario conditions in which strategic assessments are performed to include basic constraints on force operations, the impact of alternative attack strategies (especially as Soviet strategy may differ markedly from U.S. views about nuclear warfare), and the importance of C^3, attack assessment, force reconstitution." [13: 74]

The next study reviewed here addresses the subject of escalation control in a U.S. limited nuclear attack. This study examines the U.S. targeting strategy to determine if the

Soviets could estimate U.S. intent based on the targets which were attacked and the collateral damage which would occur to surrounding targets. The "Strategic Targeting Constraints Criteria" study, published in April 1984, addressed the concept of withholding certain target classes from attack and how this restraint could be evaluated. The study acknowledged the premise that "recognizable restraint, under certain conditions, may lead to escalation control." The objective was "to determine if existing collateral damage constraint criteria are appropriate to current employment policy guidance and the supporting planning of employment options." [13: 109]

Even though these studies address pattern recognition in a general sense and do not directly discuss intent determination, the studies were still valuable in developing a methodology. The studies validated the idea that withholding classes of targets from attack could control escalation if the other side could determine the attacker's intent from the target class attacked and the collateral damage to surrounding targets. This idea is an important point because it is the real motivation for the research. **If intent determination can not be determined, then a limited nuclear attack will quickly escalate into an all-out conflict by both sides.** At the present moment, the U.S. attack assessment and characterization system does not explicitly provide intent determination information. The purpose of this thesis is to develop a methodology for providing that information.

Interviews with missile warning experts provided the other major source of relevant background information. Some of that information has already been presented in chapter I in the "current situation" section. The remainder of the background information, obtained mostly from missile warning experts, will be presented in the next section.

Discussions with Experts

There are several key pieces of information still needed to fully understand the problem. As mentioned in chapter I, the specific problem with the current attack characterization system is that it does not contain a feature to determine intent of the attack. Not only is this feature missing, but as previously shown, the **target class summary** data collected by the system can be misleading.

Uncertainty. In order for intent to be determined, as much uncertainty as possible needs to be removed from the predicted impact point data. The uncertainty in the impact point data comes about from two sources. First, there is the uncertainty introduced by the inaccuracy of the radar systems in tracking the warhead. No radar system could ever be built which would pinpoint exactly the location of each and every warhead, but a system could be built that could get "close enough." The other major source of uncertainty in the predicted impact point data is the inherent uncertainty in the flight of the warheads themselves. Even though the missiles are launched with an aim point, due to initial error in the launch vehicle parameters, reentry vehicle imperfections, and atmospheric disturbances on the reentry, the warhead will not exactly hit its target [19: 3-5 – 3-8]. Given perfect *information as to where each warhead was going to detonate*, and if the targets were far enough apart so that there was no overlap in the the target zones, then by analyzing which classes of targets were being attacked, intent could be estimated with some certainty. This idea is central to the development of the methodology. The research objective will be met by analyzing the classes of targets which are attacked and using the results to give an estimate of intent. Then the methodology for determining intent will be used to find the sensor accuracy necessary to give specified levels of correctly-classified warheads in the attack characterization.

This accomplishment of intent determination requires two premises. First, that an accurate prediction of impact point can be determined and second, that the specific targets and their classes could be correctly determined and reported. Inherent in this theory of intent determination are the assumptions that the Soviet missiles are accurate enough within reason to hit the target they aim at, that the Soviets would use only one warhead per target, and that the Soviets would attack with a specific strategy.

The first assumption seems valid based on information collected from Soviet test launches. Their missile accuracies have increased over the past decade and they are now able to hit their targets within a few hundred meters. The reported CEPs of the SS-18 and SS-19 which are the latest Soviet ICBMs are 300 meters [14: 164]. An error of only 300 meters due to launch parameter error and reentry vehicle perturbations caused by design imperfections and atmospheric disturbances will not adversely affect the determination of intent.

The next assumption concerns targeting strategy. It is assumed that the Soviets would use only one warhead per target and that each warhead would be aimed at only one target. Both of the postulates seem reasonable. In a limited nuclear attack which is the scenario of interest in this research, it does not seem reasonable that the Soviets would expend such a small number of warheads (10 to 20) and then use more than one warhead on any one target. Depending on their intent with the attack, using more than one warhead per target would decrease the likelihood that their "message" would be understood. Instead of using more than one warhead on any one target they would probably send a few more warheads to attack more targets in the same target class. Also, Soviet weapons are so large in yield that very few targets exist in the U.S. which would require more than one warhead to produce a high probability of kill. The second postulate is that each warhead is aimed at only one target as opposed to being aimed between two targets so that one weapon could kill both targets. This postulate is also reasonable. Because the Soviets have thousands of warheads, using one warhead to try to kill two targets defies logic. Therefore it will be assumed for intent determination purposes that each warhead is aimed at one target and that each target is not attacked by more than one warhead.

The last assumption requires that the Soviets attack with a specific intent in mind. Their intent could be a counterforce attack against strategic military targets, a countervalue attack against cities and industrial targets, or a decapitation attack against the military command and control structure or its communications. If the Soviets randomly chose targets to attack then intent determination would be impossible because no pattern exists in the data. There would be no attack pattern to recognize, only chaos.

The first prerequisite for intent determination is accurate impact point prediction. As mentioned in chapter I, the Defense Support Program (DSP) satellites would detect and track the Soviet launch during its boost phase [5: 223; 22: 38]. At this point an estimation of impact area is made based on the heading of the missile. This estimation of impact area can be very inaccurate (as much as 180° off from the true heading) due to certain observation phenomena [30]. The DSP satellite reported impact points have a one standard deviation of 10 kilometers in azimuth and 400 kilometers in range [4: 191]. This implies that the DSP data could be used to determine what east-west portion of the United States was under attack but would not be reliable in a north-south determination. For California, the target area of interest, this impact prediction data would not be very useful in determining intent as shown in Figure 2.1. The area of uncertainty would simply be too large to get an accurate assessment of what target classes were under attack.

Three to four minutes after detection, the DSP satellites would lose track of the missiles. The U.S. would be blind to the attack and its nature until the reentry vehicles could be detected by the ground-based radar systems. At about 15 minutes before impact, the warheads would be detected by the Ballistic Early Warning System (BMEWS) and more precise tracking would begin. When an object is first detected by the radar it is not known if the object is an orbiting space vehicle such as a satellite or an attacking warhead.

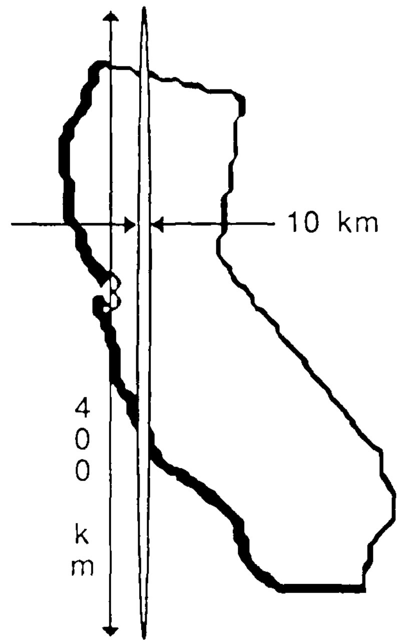

Figure 2.1 Area of Uncertainty from DSP data

The object is assessed by the computer software at the radar location to determine if its trajectory is orbital or reentry. If the trajectory is reentry the object is compared with the catalog of objects in the radar's computer to determine if it matches a known orbiting object. This determination is not always conclusive. If it can not be determined if the object is orbiting or reentering the earth's atmosphere, TG-1 tracking is initiated. In this tracking phase, the radar catalogs specific information about the object such as launch point and predicted impact point. It is in this phase that decoys would be separated from actual warheads using various parameters based on specific Soviet reentry vehicle characteristics. The final tracking phase is designated TG-2. In this tracking phase the best information is obtained about the reentry vehicle. At this time, impacting object reports (IORs) would be sent to NORAD for each reentry vehicle [22: 44].

These impact object reports contain the predicted impact points of the warheads. These are the predicted impact points which will be used by the current computer algorithm to determine what target zones are affected. The accuracy of these predicted impact points are reported to be roughly 10 to 20 kilometers from the actual intended target [30]. This accuracy is for predicted impact points 10 to 15 minutes before actual impact. The final impact points are much closer to the intended target and is measured as CEP (Circular Error Probable). The CEPs of Soviet missiles are within a few hundred meters. From predicted impact points and target zones, the specific target and its class are identified and reported on a display to the missile warning officer.

Target "at risk" Determination. The other area where the current attack characterization system is deficient is in target "at risk" determination. As discussed in chapter I, the current computer algorithm attempts to match an impact point with a target zone. Once a target zone is found in the target data base, that target code and class are displayed on a missile warning officer's console. If more than one target zone are found in the data base which contain the impact point then all of the target codes are displayed on the missile warning displays. As previously discussed, this assumes sort of an equal weighting for all targets regardless of the level of the damage on each target. To understand this further requires knowledge of how target zones are constructed.

A target zone is the area surrounding a target in which if the impact point lies in that area, the target is assumed "killed" and if the impact point lies outside this area the target is "safe." If the target is killed then it is reported as a target at risk and its target class is reported on the display panel. The problem with this method is that it employs the "cookie cutter" technique to determining target survivability. This techniques assumes that if a warhead detonates within some distance of a target which would give a certain level of damage due to nuclear effects then the target is destroyed otherwise it is safe [6]. This threshold approach causes uncertainty because in reality, a target will even be slightly damaged from a warhead detonating several kilometers away. In contrast, depending on the target hardening, a warhead might have to detonate very close to be inside the target zone. A much more realistic approach seems to be to consider the damage as a continuous function of range. The most commonly accepted model is to consider probability of survival a function of range as the cumulative lognormal as shown in Figure 2.2 [7].

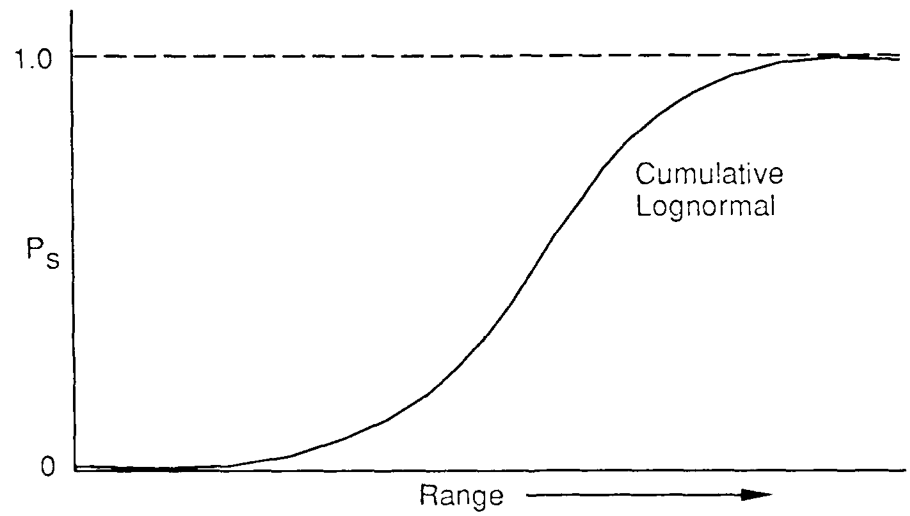

Figure 2.2 Probability of Survival vs. Range

The probability of kill is just the complement of the probability of survival. The probability of kill, P_k can be calculated by equation 2.1 where the two parameters α and β are calculated by equations 2.2 and 2.3

$$P_k = \int_0^l \frac{1}{\sqrt{2\pi}\,\beta z}\; e^{-1/2\left(\frac{\ln z-\alpha}{\beta}\right)^2} dz \qquad [2.1]$$

$$\alpha = \frac{1}{2} \ln \left(I_{sk} \cdot I_{ss} \right) \qquad [2.2]$$

$$\beta = \frac{1}{(2)(2.054)} \ln \left(I_{sk} \, I_{ss} \right) \qquad [2.3]$$

I_{ss} is the intensity of the nuclear effect which at that level and below, the target is considered to be sure-safe and receive no appreciable damage. I_{sk} is the intensity of the nuclear effect at which level and above, the target is considered to be sure-killed [8]. By using equations 2.1,2.2, and 2.3 a continuous range of P_k can be obtained for the targets in the data base which are near the predicted impact point of the warhead. This approach allows a better estimate to be made of the intended target.

Under the current system's operation, once the target zones have been compared to each predicted impact point and target classes have been reported, the system begins to iterate back through the whole process of impact point prediction and target at risk determination. This whole process takes between 30 seconds to 1 minute when the number of reentry vehicles is small (less than one hundred). The target at risk and target class summary information would then be forwarded to NORAD and other high level military command and control centers.

CINC NORAD and his advisors would use this information and the "system confidence" to generate a CINC NORAD assessment. As much as possible, this assessment would need to contain a report assessing the confidence that an attack is really occurring and if so, what type of targets (which implies intent) are being attacked.

The system confidence is an evaluation of how confident and reliable the system is with respect to its operation and reporting that an attack is underway. The radar site's assessment of each reentry vehicle is reported as "valid," "false," or "under investigation." This information is combined for each of the sites which detect the reentry vehicles to provide an overall system confidence of "high," "medium " or "low." [30] For instance, if the Ballistic Missile Early Warning Systems (BMEWS) radars (Site I in Thule Greenland, Site II in Clear Alaska, and Site III in Fylingdales Moor in England [23: 252]) all detected the same reentry vehicle and two out of the three sites were reporting "high" confidence, then the system confidence would probably be assessed as "high." This system confidence would be reported to NORAD where the CINC and his advisors would generate the CINC NORAD assessment.

Absent in all of this information is a method for determining intent. Without intent determination, CINC NORAD's assessment is not as useful as it could be to the NCA. In a limited nuclear attack scenario, an estimation of the enemy's intent could be the most important information CINC NORAD could provide outside of the determination that some type of attack against the United States is occurring. It is the objective of this thesis to develop a methodology for determining that intent information. To do so will require data to be generated. The data will be used to conduct experiments to accomplish the research subsidiary objectives. Accomplishing the subsidiary objectives will directly lead to accomplishment of the research objective. The next chapter will specify the data that will have to be generated or obtained in order to accomplish the research objective. Chapter III will discuss the models which will be used to generate the data for experimentation.

III. Data Generation

Overview

This chapter will discuss the data needed to meet the research objective. The overall research objective is supported by several sub-objectives. Each sub-objective will be examined with respect to the specific data needed to for its accomplishment. Examples of the desired data will be given for each objective. A major portion of the chapter will be devoted to discussing the three models which will be used to produce the data necessary to conduct the research. Each model will be examined by its purpose, the data and parameters needed to support the model, and evidence of the model's verification and validity. Finally, an overview will be presented which discusses how the data from the three data generating models will be integrated and used in a methodology for determining intent.

Data Needed to Answer Research Questions

The desired end result of the thesis is that a methodology be developed which could indicate the intent of the Soviet limited nuclear attack. This objective can be accomplished by developing a technique which would give CINC NORAD an accurate estimate of what classes of targets were under attack. This estimate of the intent would be in the form of a report of what proportion of the attack was against each class of targets with a confidence interval around those estimates. This data would change every 30 seconds or so as new estimates of impact points were computed. The final output will be the data for the 6 minute point prior to first impact. Table 3.1 gives a sample of the output in its final form.

TABLE 3.1 Class Under Attack Estimates
(90% confidence level)

Class	Lower Bound	Point Estimate	Upper Bound
1 City/Industrial	.2000	.3100	.4000
2 Other Military	.0000	.0400	.0667
3 Strategic Military	.0000	.0660	.1333
4 Critical CCC	.5000	.5900	.6667

These estimates of the proportion of the attack which is against each class of targets would give CINC NORAD a good indication of the Soviet intent. Given the sample data presented in Table 3.1, it would appear that the Soviets intended to attack critical command and control, or communications targets and that there was a fairly high degree of collateral damage to the surrounding populated areas. Other attack scenarios would obviously yield different sets of proportions with different lower and upper bounds on those proportions. The amount of data and calculations to arrive at the final table of proportions is quite large. This large amount of data is currently being produced or capable of being produced by the attack warning and characterization system. There are also some other types of data required to answer the research objectives which are not currently being produced. In the sections which follow, each research sub-objective will be examined with respect to the data needed to support it.

The first research sub-objective is the following: Develop a Measure of Effectiveness (MOE) which can be used to evaluate prospective methodologies for determining the intent of a limited nuclear attack. The best MOE for this objective is probably a "confusion matrix." [15: 371] This table of actual intended target versus predicted intended target gives a good estimate for the accuracy of the developed methodology. Table 3.2 presents some simulated data to show how the results might look under one scenario.

TABLE 3.2 Classification Results

Actual Tgt Class	Number of warheads	Predicted Target Class 1	2	3	4
1	5	4	0	0	0
2	0	0	1	0	0
3	0	0	0	1	0
4	11	0	0	0	9

Percentage of targets correctly classified = 86.67

The results in table 3.2 would indicate that the methodology is reasonably good at classifying warheads to their intended target. In an actual attack the U.S. would really never know the actual intended target class which is why the proportion of class under attack data can only be point estimates with confidence intervals. In the research for a methodology the experiment can be controlled and the actual intended targets known. This confusion matrix will be computed for several different scenarios. The proposed methodology will be evaluated using the confusion matrix as the Measure of Effectiveness.

The second research sub-objective is: Find the sensor accuracy needed to enable the missile warning system to provide attack characterization at the 75, 90, and 98% levels of correctly-classified targets. The data used to meet this sub-objective will be the sensor data which is composed of the measurements of the reentry vehicle's position and velocity in a three axis coordinate system. The accuracy of the sensor will be varied along these six parameters (X, Y, Z, V_x, V_y, V_z) and the results evaluated with the MOE. The MOE is the percentage of targets correctly "classified" according to intent. By improving the accuracy of the sensors, the percentage of targets correctly classified can be made to increase to the different levels of attack characterization effectiveness. There will be a set of six parameter values for sensor accuracy at each different correctly-classified level.

The third sub-objective is: Analyze how missile accuracy (CEP) affects attack characterization. CEP is a parameter which can be varied to give different attack proportion estimates and different MOE values. The results of this objective will be a plot of the set of MOE values attained over different missile accuracies.

The fourth and final sub-objective is: Given the most accurate missile warning system possible, determine the longest time before first warhead detonation at which the attack characterization could be determined at the 98% confidence level. The result of this objective will be a time before first impact such as 555 seconds.

In order to meet the four research sub-objectives which support the overall research objective, some simulated data must be generated. Simulated data must be used in the analysis because actual data does not exist. One set of actual data and three generated data files were used to support this research effort.

The actual data is the set of targets in the area of interest. This data set is contained in Appendix A and consists of a target identification code, the target type (Classes 1 through 4), target latitude, target longitude, and the name of the target. This actual data set was compiled by hand plotting the targets using aeronautical maps [1]. This target data base is unclassified because it is not the actual data base which is contained in the computers at NORAD. It is however, very realistic in that actual military targets and command and control, or communications targets were located on the aeronautical maps and plotted. The cities were selected by population. Any city with 50,000 or more in population was considered a possible target of a Soviet attack and therefore was loaded in the target data base.

The first simulated data file is the set of reentry vehicles. A simulation model was developed that would create an attacking force of Soviet missiles and their reentry vehicles. A sample of one such attack is contained in Appendix B. This data set was used with another simulation model to generate a file of predicted impact points. Appendix C contains sample output of the predicted impact points. Finally, the predicted impact point data was used by another model to measure the damage as probability of kill, P_k. Appendix D contains sample output of the probability of kill data. The file of P_k values is then used by the developed methodology to answer the research objectives. These files of simulated data were thus necessary to conduct the research. The next section discusses each of the models which were used to generate the simulated data.

Models Used

There were three programs written or modified to generate the required simulated data for this research. A model written in Simulation Language for Alternative Modeling (SLAM) [33: ix] is used to generate the attacking warheads and models written in FORTRAN are used to predict impact points and estimate damage in the target area. Each of these programs will be discussed in some detail. The purpose of each simulation model will be explained followed by a discussion of the data needed to support that model. Finally, evidence of each model's validity will be presented.

Attack Simulation Model. The first simulation model that will be discussed is the model used to generate the attack. SIMATTACK.SLAM was written in SLAM and is called from a FORTRAN main program, SIMATTACK.FOR. The listing of the source code for this model is located in Appendix E. The model was written using SLAM because of the need to have the missiles take off at different times and the desire to have the attack randomly select targets at which to aim. SLAM incorporates both desired features rather easily as demonstrated by the fact that the code required to generate the attack is barely 100 lines long [33: 73-74].

Purpose. This simulation model is used to create the attacking warheads. Once the attack is "launched," the warheads can be simulated in flight toward the target area. The launch of the attack can be made to occur from any place in the Soviet Union and consists of any number of weapons. A sample attack is contained in Appendix B. The model generates a data file which contains a reentry vehicle number (1 through size of the attack), latitude and longitude of the launch site, latitude and longitude of the intended target, relative time of launch in seconds, target class attacked (1 through 4), and the target identification code.

Data Needed to Support Model. There are several parameters which can be changed to alter the nature of the attack. First of all, the total number of weapons can be altered by changing the number of entities created in the network. The relative time between launches can also be changed at the CREATE node. In the particular attack shown in Appendix B, an SS-18 was launched from Omsk with 9 independently targeted warheads onboard. Simultaneously, a second missile was launched, an SS-19 from Teyhovo with 6 independently targeted warheads. Each warhead (total of 15) was assigned a different target in the target data base. The target data base is in a file called REALTGT.DAT and is read into the attack generation model. The model as written allows a great deal of flexibility in choosing the size of the attack and the origination of the attack. By changing parameters in the SIMATTACK.SLAM portion of the model, a different set of targets could be attacked. Changing the values in the ACT arcs after the first two GOON nodes affects the nature of the attack. The attack can be made more heavily counterforce than countervalue or a total decapitation attack can be attempted. These attacks would be selected by changing the proportion of each class of targets attacked. The model allows testing of all the parameters of interest under the experimental design.

Evidence of Validity. The model was validated by changing various parameters and examining the results. In all cases the model returns reasonable data. By referring to Appendix B it can be seen that targets from all four target classes are attacked under the uniform attack plan. It can also be seen that targets are selected at random ranging from 5, Bakersfield, all the way to the one of the last targets in the file, 141, the

Ground Wave Emergency Net (GWEN) input node at March AFB. By comparing the selected target number, its latitude, and longitude to the data in the target base in Appendix A the integrity of the attack is validated. The model is accepted as producing valid attack data.

Trajectory Simulation Model. Once an attack has been launched, the missiles will eventually be detected and tracked by BMEWS. The trajectory simulation model called TSP performs this simulated detection and tracking by the ground-based radar systems. The model is written in FORTRAN and was adapted from a model obtained from the Foreign Technology Division (FTD) at Wright-Patterson AFB Ohio. The program was written by FTD to generate the launch parameters of a Soviet ICBM launched against any target in the world [27; 28]. The model, as part of its calculations, updates the reentry vehicle's position and velocity at each step (time) interval. Since knowing a reentry vehicle's position and velocity are all that is needed to simulate its flight, the program can be modified to "track" the reentry vehicle from detection point to impact. A listing of the adapted source code for the trajectory simulation model TSP is contained in Appendix F.

Purpose. As alluded to, this simulation model was needed to take the launched reentry vehicles and "fly" them to a point at which they could be detected by the radar system and tracked to impact. The main function performed by this program after it was modified is that at any point in time, given the reentry vehicle's position and velocity in a three axes coordinate system, an impact point can be **predicted**. This feature of the model is its main purpose. Without the ability to predict impact points in the area of interest, the research could not have been completed. A sample of this model's output is contained in Appendix C.

Data Needed to Support Model. The attack data contained in ATTACKDATA.DAT is read into the model and used to drive the simulation. Each reentry vehicle is taken and "flown" from its launch point to its impact point. At approximately

900 seconds (15 minutes) prior to impact, the reentry vehicle is detected by the radar in subroutine UNCERT (for uncertainty). There is a one standard deviation of 15 seconds on the detection time. After the reentry vehicle is detected, its position and velocity are measured by the radar. Due to radar inaccuracies, an inexact reading is obtained for the vehicle's six parameters (X, Y, Z, V_x, V_y, V_z). The program then computes an impact point **based on the measured position and velocity** which is uncertain. This computation will yield an uncertain impact point. This predicted impact point along with other relevant data is then written to a file called IMPEST.DAT which will be used by another model to calculate predicted target damage. A sample of IMPEST.DAT is contained in Appendix G. The model then reiterates through the entire process again for each of the remaining reentry vehicles in ATTACKDATA.DAT.

The model has several parameters which can be varied. The most important parameters are those dealing with the accuracy of the radar since that is a main interest of the research. The radar accuracy is changed by altering the one standard deviation values for the six parameters associated with the reentry vehicle's position and velocity. Another set of parameters can be changed to yield different missile accuracies. Essentially the same six parameters are affected but the error due to reentry vehicle's flight is introduced at different parts of the model than where the radar uncertainty is introduced. Radar inaccuracy and reentry vehicle flight perturbation are the only sources of uncertainty which affect predicted impact points.

Evidence of Validity. A great deal of testing was done to ensure model validity. It was recognized that bad data at this point would severely damage the research progress and overall validity. After extensive testing, the model was accepted as producing valid results. There were three areas of concern which required extensive validation effort.

These three areas were that:

1. The model would produce impact points which converge to the actual intended target location. As the reentry vehicle gets closer to the earth, the effect of the error in the radar's measurement is not as pronounced because the distances involved are much smaller. It would seem reasonable that the predicted miss distance would become shorter over time because the location and destination of the reentry vehicle would become more certain over time.

2. The model predicts impact points which are removed from the intended impact point by a "reasonable" distance. How realistic are the predicted impact points?

3. Given "perfect information" which would be error-free radar measurement, the predicted impact point is consistent with the missile CEP. This checks the capability of the trajectory simulation program to correctly "fly" the warhead to its target.

Data will be presented in each area of concern to support the assertion that the model is valid. The data presented is for the baseline radar accuracy which is state-of-the-art 1987.

The first area of concern was alleviated with plots of the predicted impact points over time. Figure 3.1 shows "time to impact" plotted against "latitude." The "x1" near the intersection of the two axes is the intended target's latitude. As you can see from Figure 3.1, the variation in the predicted impact points decreases as the reentry vehicle gets closer to impact. Time moves from a higher value to a lower value because time is taken to be "time before impact." The "closing megaphone" is indicative of a non-constant decreasing variance [29]. The data shown is for one warhead under one attack scenario but it is indicative of all of the predicted impact point data. The figure illustrates the intitial variance is between 20 to 35 kilometers but as the warhead gets closer the variance decreases to a few hundred meters until finally it becomes the weapon's CEP. Once warheads have started detonating and the attack warning system starts performing damage assessment, intent will be easier to determine. The problem with waiting until warheads have detonated is that the limited attack could prevent U.S. retaliation especially if the attack was against U.S. command and control or its military communications. Figure 3.2 shows similar results. From the data presented, the model appears to be generating valid data with regards to the first concern.

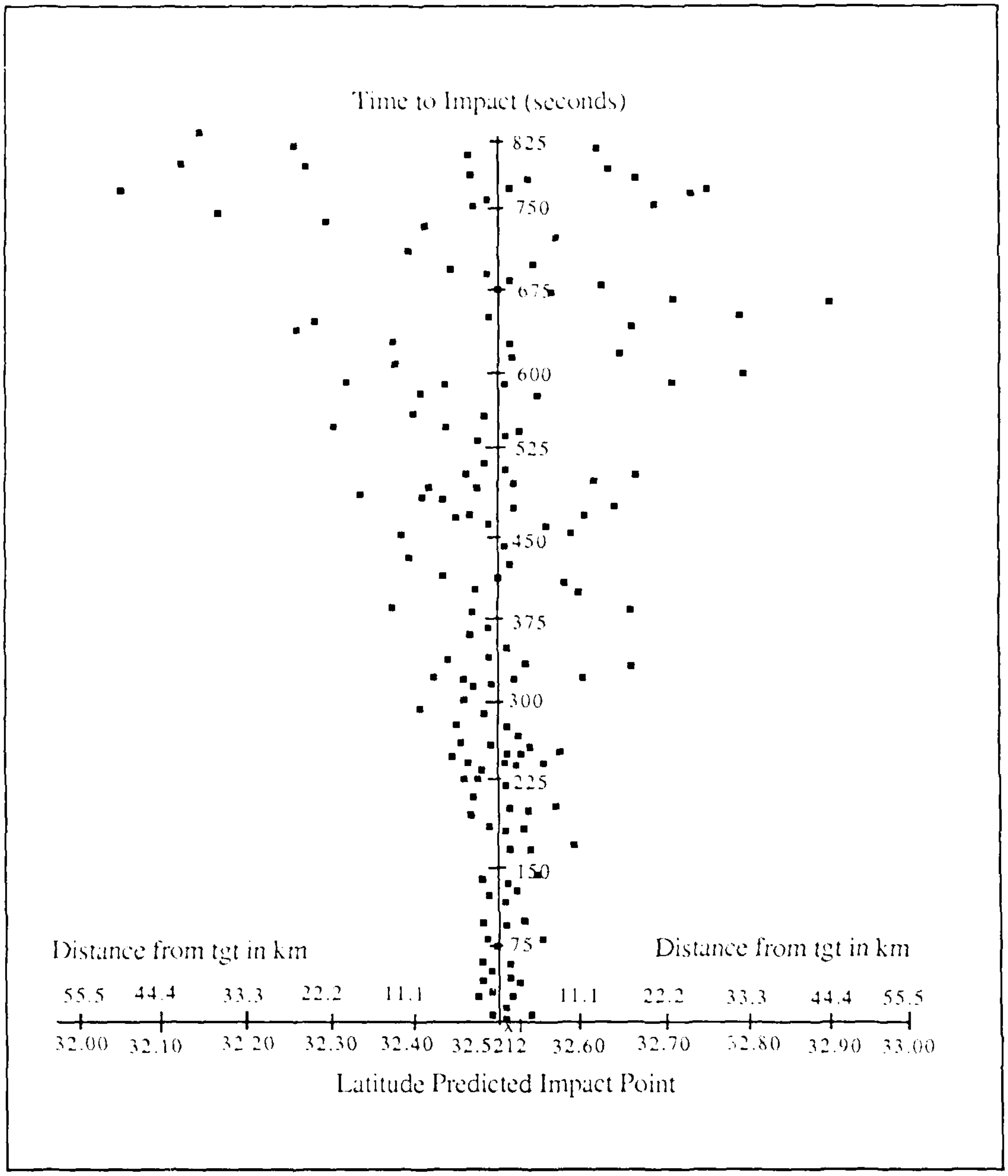

Figure 3.1 Time to Impact vs. Latitude

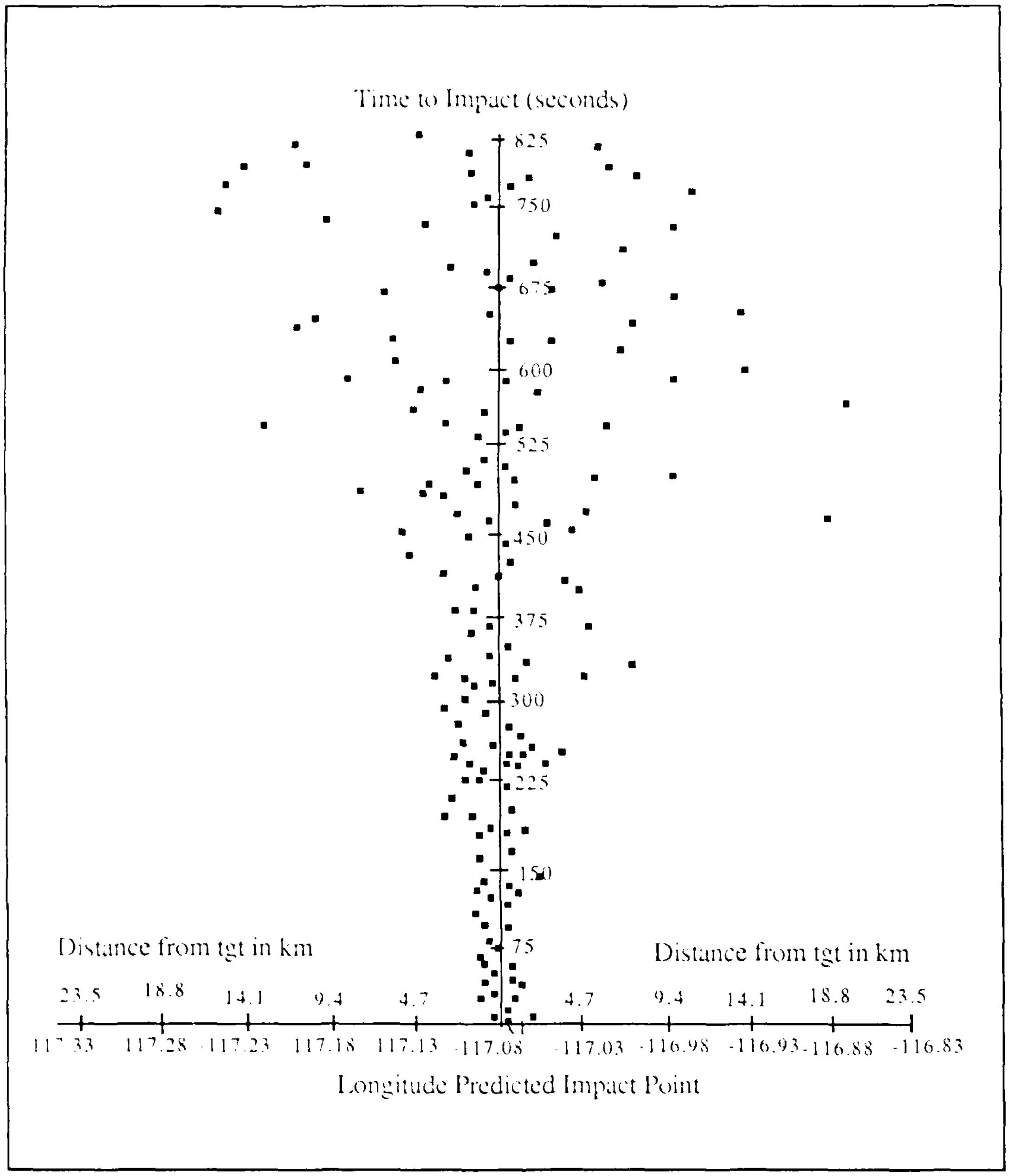

Figure 3.2 Time to Impact vs. Longitude

The second area of concern was alleviated through the Turing test. The Turing test is essentially a validation test where the generated data, interspersed with real data, is given to an expert . If the expert cannot tell the difference between the generated data and the real data, then the simulation model which produced the generated data is considered valid [3: 401]. A range of miss distances from the predicted impact points of the model were given to a missile warning officer who validated them as "consistent" with what the current radar and missile warning system would produce [30].

The last area of concern was alleviated through a simple test of reasonableness. The model, with perfect radar measurement, was run one hundred times and the impact point data collected. The warhead was tracked until it impacted the ground and the miss distance from the closest target was measured. Out of one hundred trials, roughly one-half (48) of the warheads impacted within the missile's CEP (300 meters). Therefore, the model is accepted as producing valid data with respect to testing its ability to "fly" the reentry vehicle to the target.

Nuclear Effects Model. The last model takes the predicted impact points and calculates a level of damage for every target in the data base. This model, like TSP, is also written in FORTRAN. The program is called NUCLEAR_EFFECTS and runs on a VAX 11/780. The program was written using algorithms supplied by Captain Michael Sabochick of the Nuclear Engineering Department at the Air Force Institute of Technology (AFIT). A listing of the source code is contained in Appendix II.

Purpose. This model reads in the file IMPEST.DAT which contains the predicted impact points of all the attacking warheads. The program then takes each predicted impact point and calculates the damage to each and every target in the target data base. The damage calculated in the model is due to two nuclear effects, blast overpressure and thermal radiation. The damage due to each effect is then converted to a probability of kill, P_k by using equations 2.1, 2.2, and 2.3. The P_k is found for each effect and then combined together to give an overall P_k for the encounter. If the P_k is above 0.005 then it is written to a file PSTEST.SAS for further use. This model essentially measures from a damage point of view, how close the warhead is coming to its intended target. It also shows the collateral damage to the surrounding targets. A sample of the model's output is contained in Appendix D.

Data Needed to Support Model. As previously mentioned, the damage calculation model NUCLEAR_EFFECTS reads in the predicted impact point data as one of its inputs. It also needs the yield of the weapon and the height of burst which can be treated as parameters and changed. There are four sets of four hardness parameters which can be varied to change the model's results. Each of the four target classes has a set of hardness parameters which can be varied for experimentation. The fifth target class, Washington, D.C. is not included because the target class is not present in the target area of interest.

The four hardness parameters are OVPISS, OVPISK, THERMISS, and THERMISK. OVPISS represents the blast overpressure value below which the target is considered sure-safe. This sure-safe value is taken to be a probability of kill of 0.02. OVPISK is the blast overpressure value above which the target is considered sure-killed. The probability of kill associated with sure-kill is 0.98. THERMISS is the thermal radiation value associated with sure-safe and THERMISK is the value for sure-kill. These four parameters will be different for each target class because each type of target would have a different response to a given level of nuclear effects. These parameters in effect change the size of the target zones. A hardened target will require the warhead to detonate much closer to attain the same probability of kill which a less hardened target would experience much further away.

Evidence of Validity. The algorithms from which the damage calculation model was written have been developed and tested by the Nuclear Engineering Department at AFIT [37]. The results from these algorithms have been validated during two quarters of nuclear survivability courses from 31 March 1986 to 11 July 1986. An inspection of the data in Appendix D shows the results to be reasonable.

As the range increases between the target and the impact point, the P_k generally decreases. This inverse relationship generally exists because the nuclear effects diminish as the reciprocal of $Range^2$. However, this relationship is not an absolute because of a phenomenon associated with the thermal effects. There is a time lag involved with thermal effects. The maximum thermal radiation value does not occur at the same range as the maximum blast overpressure value [38]. This explains the apparent anomalies in the data when the P_k does not always decrease with the range. This anomaly is small and insignificant in determining the overall probability of kill.

Another proof of model validity is a comparison of the calculated overpressure values with predicted values. The model results were compared with figures 3.73a, b, and c of *The Effects of Nuclear Weapons*. There was good agreement between calculated results from the model and predicted results from the nuclear effects tables [18]. The model is accepted as providing valid data.

Overview of Using Model Results to Determine Intent

The volume of data generated by the three previously discussed models are of little value without a methodology to take that data and from it determine intent. Chapter IV will discuss the development of the methodology to combine the calculated damage with intent determination. The methodology determines how the estimates of intent are changing over time as the data becomes more certain.

Figure 3.3 shows each of the data files which are used and generated by the three models previously discussed. As is shown in the figure, the data generated by each model is used to drive the next model in sequence until finally a data file is produced containing probability of kill information for each target from each warhead at 30 second increments. This last data file is then used by the methodology to generate results for the research objectives.

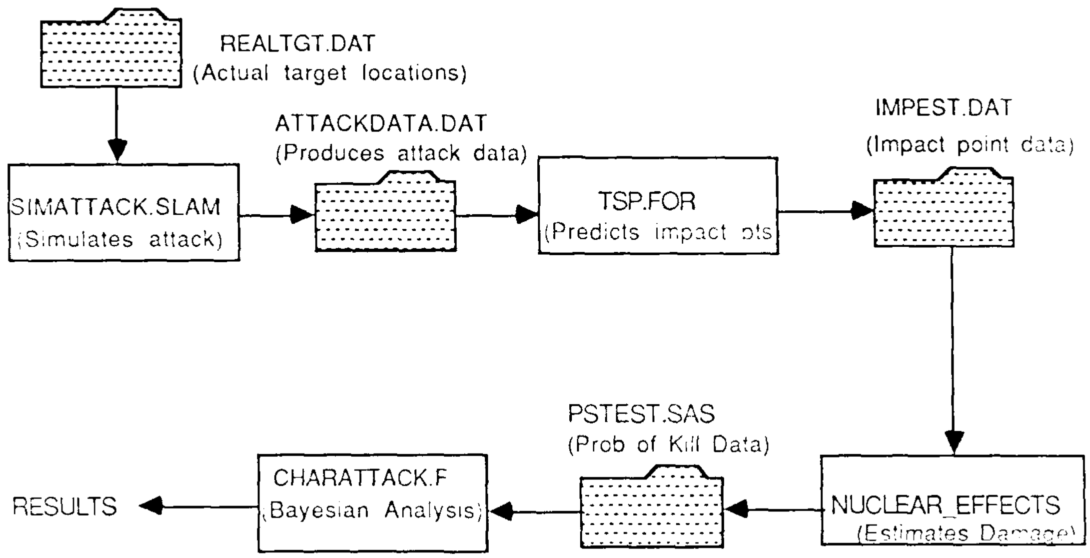

Figure 3.3 Data Flow

Chapter IV will contain the methodology development, a description of the test hypotheses and conditions, and the plan for meeting each research sub-objective. The theoretical foundation for the methodology will be presented along with how the data from the models will be used to generate intent estimates. Each test hypothesis will be stated along with the conditions of the test to include the expected results. Finally, the chapter will conclude with a discussion of the experimental design used to support each of the research objectives.

IV. Methodology

Overview

This chapter contains a thorough discussion of the methodology chosen to meet the research objective. The chapter begins by first reviewing some of the methodologies which could have been used to solve the intent determination problem. Each methodology will be examined for its features and evaluated for its applicability to the problem of interest. The reasons for eventually rejecting the methodologies not chosen for problem solution will be discussed. After all non-selected methodologies have been examined, the chosen methodology will be introduced. The theoretical basis for selecting Bayesian analysis as the methodology for problem solution will be developed. Past uses of Bayesian analysis in solving problems will be reviewed as support for selecting Bayesian analysis as the methodology for this research. Then the mechanics of using Bayesian analysis will be illustrated with a detailed example using some of the generated data from the research. The last part of the chapter discusses the test hypotheses and conditions for answering each of the research objectives as part of the experimental design for conducting the research.

Methodologies Investigated

There were three general methodologies or approaches which were investigated for their applicability in determining the intent of a limited nuclear attack. The first two methodologies which will be discussed in this section are the ones which were not chosen to solve the problem. These general methodologies or approaches are cluster analysis and discriminant analysis. Both of these methodologies will be reviewed for their applicability and then shown why they were rejected. The methodology which was chosen, Bayesian analysis, will be discussed last. Since Bayesian analysis is the methodology used to solve the problem of this research it will be examined more thoroughly than the other two methodologies.

The problem of determining intent from a limited nuclear attack involves pattern recognition. It is ultimately CINC NORAD's responsibility to "recognize" the type of attack occurring from the indications being received at the missile warning center. He must then relay this information to the National Command Authority with as much confidence as possible. Attack pattern recognition is currently made more difficult because the data is not presented in an appropriate format and because no attempt is made to deconflict or resolve the individual warheads onto their intended targets. The current system simply does not support attack pattern recognition.

Pattern recognition involves two goals. The first goal is "separating distinct sets of objects" and the second is to "allocate new items to previously defined groups." [35: 9] Deconflicting or allocating warheads to a specific target as their intended target is an example of the second goal. The previously defined groups are the four classes of targets and the new items are the individual attacking reentry vehicles. The first goal has been referred to in the literature as "discrimination" and the second as "classification." The multivariate analysis technique of discriminant analysis is used to "discriminate" sets of objects from one another. One of the available classification techniques is cluster analysis. For these reasons, cluster analysis and discriminant analysis were investigated as possible methodologies for solving the research problem. One usually thinks of "discriminating" things from one another before an attempt is made to classify new objects. Although the logical order of discussion would be discriminant analysis before cluster analysis, the order of discussion will be reversed here since cluster analysis was the first problem solving methodology attempted during the research.

Cluster Analysis. "The most commonly used term for the class of procedures that seek to separate the component data into groups is cluster analysis." [15: 157] One of these procedures is the "single linkage or nearest-neighbor method." [15: 168] This method was recommended by Lt. Col. Lawhern as a possible methodology for solving the research problem [26]. Other possible cluster analysis procedures such as average link and Ward's Error Sum of Squares method also looked promising.

Features. Nearest-Neighbor and the other methods have as a main feature the property of grouping things together based on some type of measure between the prospective objects of a group. In the case of nearest-neighbor the measure is minimum distance. The method begins by first finding the two objects with the shortest distance between them and then grouping the two objects together as the first cluster. At the next stage, either a third object joins that cluster because of its proximity to it or two distinct objects will cluster together to form a second cluster. This process continues until all objects have joined a single cluster [15: 168]. Distinct clusters can be obtained by selecting some distance as the stopping point for clustering objects together.

The way this procedure would work for the limited nuclear attack scenario is that first all of the targets would form clusters and then the warhead's predicted impact points would be made to join a cluster based on the minimum distance criteria. Warheads then would be considered as having attacked the cluster to which it is a member and therefore the targets in that cluster would be considered the intended targets. This methodology is feasible given the data which is currently being generated. Unfortunately, the cluster analysis approach fails to solve the research problem for three reasons.

Reasons for Rejection. First, cluster analysis assumes no *a priori* number of groups. In the problem area of this research, the number of groups has been predetermined by the military command structure. In the geographical area of interest, there are four defined groups (city/industrial, other military, strategic military, and C^3).

The problem of attack pattern recognition requires that the warheads be "assigned" to one of these four target classes. The nearest-neighbor procedure which allows the targets to "naturally" cluster together would certainly not yield only four clusters in an area containing 148 targets. This result would then require some manipulation to make the nearest-neighbor procedure useful as a classification tool given the problem environment.

Another reason the cluster analysis method is unsuitable is because the procedure uses distance as a criteria for grouping. During the early stages of the research it was thought that the warheads could be classified or assigned to a target based on a minimum distance criteria. Then it was discovered that the damage that each target would experience due to a nearby detonating warhead is dependent on distance but that the dependence is not the same for all classes of targets. Cities and industrial targets would be damaged more than a hardened strategic target if a warhead were to detonate the same distance away from both targets. Probability of damage could have been used as the "measure" of distance but this technique would have required a great deal of manipulation. In addition, the other problems with using cluster analysis as a solution methodology would still exist.

Finally, the last reason cluster analysis is not appropriate as a solution methodology is that because of the mix of targets in the area of interest, all the targets in a particular cluster might not be of the same class. This fact means that some additional technique would need to be used to determine which in the cluster of targets was the actual intended target and target class. This result comes back to the original problem!

Therefore, for the three reasons just discussed, cluster analysis was determined not to be suited for solving the problem of interest. The nature of determining the intent of a limited nuclear attack is a classification problem of sorts but the traditional methods of classification will not work in the problem environment. The next approach which was attempted as a solution methodology was discriminant analysis. This technique like cluster analysis comes from the field of multivariate analysis. The next two sections discuss the features of discriminant analysis and the reasons for its rejection as the solution methodology.

Discriminant Analysis. The first goal of pattern recognition is to separate distinct sets of objects from one another by finding some characteristic of the objects which can be used to separate them. This goal can be achieved by finding a discriminant function which does a "good" job at distinguishing between objects in different groups. Discriminant analysis seemed like a reasonable methodology to employ after the use of cluster analysis proved fruitless. It was thought that certain parameters of the attacking reentry vehicles could be identified and then be used to build a discriminant function. This function would then be used to classify each warhead as being "assigned against" a particular target and consequently a class of targets. The next two sections discuss some specific features of discriminant analysis and the reasons why this approach, like cluster analysis, failed to be appropriate for determining the intent of a limited nuclear attack.

Features. By definition, "*Discriminant analysis* is a statistical technique for classifying individuals or objects into mutually exclusive and exhaustive groups on the basis of a set of independent variables." [15: 360] It works by "deriving linear combinations of the independent variables that will discriminate between the *a priori* defined groups in such a way that the misclassification error rates are minimized [15: 360] From the definition and the explanation of how discriminant analysis works the method seemed to be applicable to the research problem. The groups or classes of targets are defined *a priori* and each warhead will be assigned to one and only one group making the groups mutually exclusive and exhaustive. The measure of effectiveness (MOE) chosen for the research is the percentage of targets correctly classified. By maximizing this quantity, the misclassification error rate will be minimized because they are complementary. Everything thus far seemed to support the use of discriminant analysis as the solution methodology. Other features of discriminant analysis will now be discussed with respect to using this method to solve the research question.

Discriminant analysis can be viewed as a simple "scoring system" which assigns to each individual or object (in this case the warheads) a score which is a weighted average of the object's values on the set of independent variables [15: 361]. The complicating factor in this problem environment is that with multiple groups (in this case four) *multiple discriminant analysis* must be used. Multiple discriminant analysis has the same goal as the two-group discriminant analysis in that a function is desired which will maximize the ratio of between-groups variance to within-groups variance.

Unfortunately, with more than two groups, a single discriminant function may not be satisfactory in distinguishing the groups. This factor would then require that up to $K-1$ discriminant functions be developed for properly discriminating between the attacking warheads [15: 394-395]. The result of needing more than one function adds to the computational complexity of the problem but the methodology could have still been used to solve the problem. Eventually two reasons surfaced which were responsible for rejecting discriminant analysis as the solution methodology. These reasons are discussed in the next section.

Reasons for Rejection. There are only three parameters of the reentry vehicles which can be measured by the ground-based radar warning systems. These three parameters are range, azimuth, and elevation. Knowing these three parameters and how they are changing allows the warhead's position and velocity in a 3-axis coordinate system to be determined. From this information, not only can the position and velocity of each warhead be determined but an estimate can be made of its impact point.

In the early phases of the research it was thought that the values of the warheads in the six predictor variables (X, Y, Z, V_x, V_y, V_z) could be used to build the necessary discriminant functions. Up to three functions would be possible using the rule that with K

groups and p predictor variables, min(p, $K - 1$) discriminant functions exist. These discriminant functions would then be used to classify new observations (warheads) into a specific group (target class). The problem with this approach is that the six predictor variables essentially interact to produce a seventh variable which is really the variable of interest, miss distance as measured from the predicted impact point to the intended target.

Regardless of how the problem was viewed, measurement of the warhead position and velocity became unimportant when miss distance was considered. It is the distance from the predicted impact point to every potential target in the area plus a consideration of the target hardness as specified by the target classes which determines the damage on each target. The damage on the target is the only real measure of what target is actually intended by a particular warhead. This point is crucial to the research effort. There is no other empirical evidence other than expected damage that will be available which will specify the Soviet's intent with respect to each individual warhead.

Since damage is a function of miss distance but dependent on the target class, using the six predictor variables as a basis for discriminant functions is inappropriate. The second reason for rejecting this methodology for problem solution is that there is no reason to suspect that the targets are clustered by type along any dimension which could be used to distinguish among the groups. Due to the random nature in which the four classes of targets are distributed, it would be an impossible task to find a dimension which would discriminate among the classes of targets. The within-groups variance is large and the between-groups variance is very small because of the way the targets are distributed in the target data base. This condition is in contrast to the goal of discriminant analysis which attempts to maximize the between-group variance to the witnin-group variance. Then, even if a dimension could be found which discriminated the targets into their four classes, attempting to classify the warhead into one of these classes would be very difficult. There simply would not be enough variation in the distributions of the classes along the discriminant axes to adequately allow discriminant analysis to "assign" the warhead to one of the classes.

Therefore, for the two reasons just discussed, discriminant analysis is inappropriate for distinguishing the warheads from one another and consequently for making a classification to a target class. This result means that discriminant analysis is unsuitable for determining the intent of a limited nuclear attack. However, the findings under this methodology can be used to identify the appropriate methodology. The clue to the correct methodology to use is in the properties of the predicted impact points. The location of a predicted impact point at one time is independent of the location at some later time but there is "information" in each predicted impact point. Over time, as the warhead gets closer to the earth, the variance in the predicted impact points decreases because the accuracy of the radar predictions improves as the objects get closer to the earth. This improvement in accuracy is due to the fact that since the warhead is closer to its impact point, there is less time and distance for error to be introduced. This decreasing variance is illustrated in Figures 3.1 and 3.2. This property of the impact points means that over time, the impact points will tend to center around and eventually converge to the actual target. By adopting a methodology that will combine together information from the various impact points, an estimate can be made about the actual intended target of a particular reentry vehicle. The methodology which uses prior information to combine with current information to give a better estimate of the true state of nature is Bayesian analysis.

Determining Intent Using Bayesian Analysis. By definition, "Bayesian analysis is concerned with the basic problem of assessing some underlying 'state of nature' that is in some way uncertain." [31: 1] Bayesian analysis assesses the uncertain state of nature in a very simple way. Consider the situation where there is a mutually exclusive and exhaustive set of events which are possible. It is known in advance that one and only one of these events will occur but which specific one will occur is uncertain. Bayesian analysis begins by assigning *prior* probabilities to the likeliness of each event occurring. Then as additional information is obtained, these initial probabilites are updated with the new information by application of *Bayes' Theorem*. The revised probabilites are known as *posterior* probabilites and have explicitly taken into account the prior information [31: 1-2].

Bayesian analysis could be applied to the research problem in the following way. The existing set of exclusive and exhaustive outcomes is the proportion of the attack which is against each of the four target classes in the area of interest. A prior probability could be assigned to each possible outcome estimating the likeliness that the attack was launched against that specific class of targets in some certain proportion. These prior probabilites could be assigned "equally." This situation would mean that there is no reason to suspect that one type of attack (counterforce, countervalue, or decapitation) would be selected by the Soviets over another. This is analogous to saying the Soviets arbitrarily selected targets from the target list and launched their attack in a random manner.

In contrast, the probability could be subjectively assigned and weighted towards a set of classes based on the current world situation and the U.S. leadership's perception of Soviet strategy. Then as information is received during the attack from sensor readings, this new information could be combined with the prior probabilities using Bayes' Theorem to generate revised probabilities. This procedure could be repeated each time as new sensor readings are received. Approximately every thirty seconds as new impact points are predicted and new estimates of expected damage are made, an algorithm could generate new posterior probabilities. With each cycle through the algorithm, the posterior probabilities at time, t become the prior probabilities for time, $t + 1$. It is asserted that due to the nature of the sensor data, it becoming more accurate over time, that the posterior probabilities would approach as a limit the "true" proportions of each target class being attacked.

At every thirty second increment, each reentry vehicle is assigned as attacking a class 1, 2, 3, or 4 target based on the relative damage caused by its predicted impact point. The damage to each target in the entire target base is calculated and the target receiving the most damage is chosen as the target and consequently the target class under attack. It should be remembered that the damage calculation is not based simply on distance from the predicted impact point to the target. The other variable affecting damage expectancy is the hardness of the target. It is recognized that choosing the target receiving the most damage in the area as the intended target ignores some important considerations. If two targets from two different target classes are very close together, it is highly likely due to the inaccuracy of the radar that there will be a higher degree of misclassification than when the targets are far apart. This matter will be dealt with later in the chapter.

The target class estimates for all of the warheads are combined to give an aggregated estimate of the number of targets from each class that are under attack. This aggregation of data is represented in Figure 4.1. The proportion of each target class being attacked is then used as an empirical measure to indicate intent. There will be an estimate of these proportions for each new set of sensor readings and impact point predictions taken over time. These estimates will be considered to be independent across the observations and therefore statistics can be used to generate a point estimate of the proportions with confidence intervals around those point estimates. This procedure will result in a table of information such as shown in Table 3.1. CINC NORAD can then use this table of information to draw conclusions about Soviet intent. The inferences he draws from this table of information will be based on the "patterns" that he recognizes in the data. This information with his recommendation for appropriate action could be passed to the National Command Authority as soon as he made his assessments of the situation. This summarizes the approach of the research methodology.

	Intent known by Soviets	Prior probabilities assessed by U S R_0	R_1	R_2	■ ■ ■	
		15 minutes prior to impact	RV performance Sensor performance	RV performance Sensor performance	**6 Minutes prior to impact**	
Reentry Vehicle # 1	0 0 1 [illegible]		1 0 0 0	0 1 0 0		
• • • •						
Reentry Vehicle # 15	0 1 0 0		0 1 0 0	0 1 0 0		
Summed over the attack (15 warheads)	2 3 4 6		0 3 2 10	2 3 0 10		Results $.03 \leq .09 \leq .15$ $.17 \leq .20 \leq .23$ $.19 \leq .25 \leq .31$ $.41 \leq .46 \leq .51$
			Bayesian Processor			

Figure 4.1 Aggregated Data

The previous discussion outlines completely the approach chosen to solve the research problem. The use of Bayesian analysis as the solution methodology can be supported through literature and examples. The next few sections will explain more deeply the theoretical foundation for using Bayesian analysis with a discussion of how the method works. Finally, the actual technique of Bayesian analysis will be demonstrated on a simulated set of data.

Theoretical Basis. Bayesian analysis is a method for combining subjective information with measured *information to construct an estimate of an unknown parameter* [24: 552-553]. The subjective information measures a person's "degree of belief" in a proposition [24: 552]. In the research problem environment the subjective probabilities would be the "degree of belief" that the U.S. leadership placed on the Soviet intent to attack each class of targets. For instance, the U.S. could believe beforehand that the Soviets intended to attack city/industrial targets with 20% of the attack, general military targets with 10%, strategic military with 15%, and critical command and control or communications targets with 55%. For each class of targets, a set of prior probabilities exist for each possible proportion of the attack. For the research scenario of 15 warheads, there will be a prior probability for the attack containing 0 out of 15, 1 out of 15, 2 out of 15,... all the way to 15 out of 15 warheads attacking a particular class. Each class will be attacked with a certain portion of the total warheads. This unknown number of warheads attacking each class, **X**, can be treated as a random variable. Because there are only 15 warheads, the observed outcome of **X** equates to a proportion, θ, which represents the proportion of the *attack which is a specific target* class. The prior belief information about the likelihood of the Soviets attacking a specific class of targets with a certain proportion of the attack is known as the prior probability. These prior probabilities will be updated using Bayes' Theorem when observed information is obtained. The updated or revised information are the posterior probabilities.

The posterior probabilities have a "cause-and-effect" interpretation to them [2: 24]. In the problem at hand, the "Bayesian question" would be something like: What is the intended proportion of the attack that is against city/industrial targets **given** the fact that 3 warheads of the attack were observed to be against city/industrial targets and the remaining 12 warheads were assessed as being against the remaining classes of targets? The next few sections show the step-by-step solution to this question. The solution to the question is obtained through application of Bayes' Theorem.

Bayes' Theorem. Mathematically Bayes' Theorem [21: 24] is shown in equation 4.1.

$$P(\theta_i|x,y) = \frac{P(\theta_i)\ P(x,y|\theta_i)}{P(x,y)} \tag{4.1}$$

In words, Bayes' Theorem states that: The probability for each possible proportion of the attack being against city/industrial targets **given** that 3 warheads of the attack were observed to be against city/industrial and the remaining 12 warheads against the other classes is equal to the product of the prior probability for each possible proportion and the likelihood that the observed value would be obtained given the attack was intended to be that proportion of city/industrial all divided by the marginal distribution of observing the sample, $x = 3$ and $y = 12$. The marginal distribution of the sample is really a normalizing constant. It is obtained by summing all the joint distributions of the sample and θ_i, where θ_i is all the possible values of θ (16 different values, 0.000...1.000) [21: 574-575]. The marginal probability of observing a particular value **X** can be calculated easily from a table of conditional probabilities of $\mathbf{X}|\theta$ provided in Table 4.2. The marginal probability is found from Table 4.2 by summing the probabilities in the column corresponding to the number of warheads assigned against the target class of interest. For this example, the correct column is under $x = 3$. It can be shown mathematically that for any given finite sample size, the Bayesian estimate of the unknown parameter will always be "shaded" towards the prior probability. As the sample size increases, the effect of the prior probability on the posterior probability decreases [24: 566]. The simplest way to illustrate the use of Bayes' Theorem is with an example.

Example. The following quantitative example is provided using simulated data. The prior probabilities in Table 4.1 would be obtained for each class of targets. These are the subjective probabilities which would be assigned by the U.S. leadership. The example presented is for the proportion of the attack against city/industrial targets. The calculations for the other three target classes follow the same reasoning.

TABLE 4.1 Prior Probabilities for City/Industrial

PROPORTION (θ)	PRIORS
0/15 = 0.0	0.0018
1/15 = 0.0667	0.0018
2/15 = 0.1333	0.0018
3/15 = 0.2	0.0018
4/15 = 0.2667	0.0018
5/15 = 0.3333	0.0018
6/15 = 0.4	0.05
7/15 = 0.4667	0.15
8/15 = 0.5333	0.40
9/15 = 0.6	0.15
10/15 = 0.6667	0.05
11/15 = 0.7333	0.0018
12/15 = 0.8	0.0018
13/15 = 0.8667	0.0018
14/15 = 0.9333	0.0018
15/15 = 1.000	0.0018

The likelihood probabilities are given in Table 4.2. These probabilities are the likelihood that the observed value would be obtained given a specific state of nature. In other words, the likelihoods are the conditional probabilities of obtaining a sample **x**, given the state of nature of 0/15, 1/15, 2/15...15/15 warheads intended against city/industrial targets. The conditional probabilities or likelihoods are obtained by treating the process as a draw with replacement from a set of possible outcomes where the outcome has two possible values, success or failure.

For 15 warheads, there is a probability of obtaining 0, 1, 2, 3,...15 warheads from a specific target class with the remaining warheads being assigned to one of the other three classes given a probability of success on a single draw. From a sample of n draws, there will be x "successes" and y (calculated by 15 - x) "failures." This process is referred to as a Bernoulli process because it is made up of a sequence of independent Bernoulli trials with each trial having only two possible outcomes [21: 129]. Each warhead will either be assessed as attacking a target in the target class of interest (city/industrial in the example) or assessed as being against a target from one of the other target classes. The number of "successes" will be the number of warheads assessed as attacking the class of interest and can be represented as a random variable **X**. The distribution of **X** has a *binomial* distribution [21: 132]. The probability density function for this distribution is presented in equation 4.2.

$$P(x) = \binom{n}{x} p^x (1-p)^{n-x} \quad \text{where } x = 0,1,2,3,\ldots n \qquad [4.2]$$

The following example shows the calculation for the conditional probability of the sensor observing 3 warheads attacking the class of interest given the intended proportion of the attack is 3 out of 15 or 0.2.

$$P(3) = \binom{15}{3} .2^3 (1-.2)^{12}$$

TABLE 4.2 Likelihood Probabilities

x, the number of warheads against class of interest

Proportion (θ)	0	1	2	3	4	5	6	7
0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
.0667	.3552	.3806	.1903	.0589	.0126	1.9841 E-3	2.3621 E-4	2.1694 E-5
.1333	.1169	.2698	.2905	.1937	.0894	.0302	7.7563 E-3	1.5342 E-3
.2000	.0352	.1319	.2309	.2501	.1876	.1032	.0429	.0138
.2667	9.5387 E-3	.0520	.1324	.2087	.2277	.1821	.1104	.0516
.3333	2.2838 E-3	.0171	.0599	.1299	.1948	.2143	.1786	.1148
.4000	4.7019 E-4	4.7019 E-3	.0219	.0634	.1268	.1859	.2066	.1771
.4667	8.0342 E-5	1.0545 E-3	6.4589 E-3	.0245	.0643	.1238	.1805	.2030
.5333	1.0843 E-5	1.8588 E-4	1.4870 E-3	7.3641 E-3	.0252	.0635	.1209	.1777
.6000	1.0737 E-6	2.4159 E-5	2.5367 E-4	1.6489 E-3	7.1499 E-3	.0245	.0612	.1181
.6667	6.9681 E-8	2.0964 E-6	2.9267 E-5	2.5365 E-4	1.5219 E-3	6.6966 E-3	.0223	.0574
.7333	2.4525 E-9	1.0116 E-7	1.9474 E-6	2.3206 E-5	1.9145 E-4	1.1582 E-3	5.3085 E-3	.0187
.8000	3.2768 E-11	1.9661 E-9	5.5050 E-8	9.5420 E-7	1.1450 E-5	1.0076 E-4	6.7176 E-4	3.4548 E-3
.8667	7.4803 E-14	7.2935 E-12	3.3186 E-10	9.3477 E-9	1.8229 E-7	2.6068 E-6	2.8241 E-5	2.3602 E-4
.9333	2.2854 E-18	4.7990 E-16	4.7028 E-14	2.8529 E-12	1.1981 E-10	3.6900 E-9	8.6097 E-8	1.5497 E-6
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Proportion (θ)	8	9	10	11	12	13	14	15
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
.0667	1.5497 E-6	8.6097 E-8	3.6901 E-9	1.1981 E-10	2.8529 E-12	4.7028 E-14	4.7990 E-16	2.28 E-18
.1333	2.3602 E-4	2.8241 E-5	2.6068 E-6	1.8229 E-7	9.3478 E-9	3.3186 E-10	7.2935 E-12	7.48 E-14
.2000	3.4548 E-3	6.7177 E-4	1.0076 E-4	1.1450 E-5	9.5420 E-7	5.5050 E-8	1.9661 E-9	3.27 E-11
.2667	.0188	5.3085 E-3	1.1582 E-3	1.9145 E-4	2.3206 E-5	1.9474 E-6	1.0116 E-7	2.4525 E-9
.3333	.0574	.0223	6.6966 E-3	1.5219 E-3	2.5365 E-4	2.9227 E-5	2.0905 E-6	6.9681 E-8
.4000	.1181	.0612	.0245	7.4199 E-3	1.6489 E-3	2.5367 E-4	2.4159 E-5	1.0737 E-6
.4667	.1777	.1209	.0635	.0252	7.3641 E-3	1.4870 E-3	1.8588 E-4	1.0843 E-5
.5333	.2030	.1805	.1238	.0643	.0245	6.4589 E-3	1.0545 E-3	8.0342 E-5
.6000	.1771	.2066	.1859	.1268	.0634	.0219	4.7019 E-3	4.7019 E-4
.6667	.1148	.1786	.2143	.1948	.1299	.0599	.0171	2.2838 E-3
.7333	.0516	.1104	.1821	.2277	.2087	.1324	.0520	9.5388 E-3
.8000	.0138	.0430	.1032	.1876	.2501	.2309	.1319	.0352
.8667	1.5342 E-3	7.7563 E-3	.0303	.0894	.1937	.2905	.2698	.1169
.9333	2.1694 E-5	2.3621 E-4	1.9841 E-3	.0126	.0589	.1903	.3806	.3552
1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000

The numbers in the calculations come from equation 4.2 and the following data:

$n = 15$
$x = 3$
$p = 3/15 = 0.2$
$q = 1 - p = .8$
$n - x = 12$

Using the same equation, the likelihood probabilities are calculated for all possible outcomes across all possible proportions and shown in Table 4.2. From reading the table, one can see that there is a .2501 probability that the sensors would observe that 3 cities/industrial targets are under attack **given** that 3/15 or 0.2 targets from Class 1 were the intended targets of the attack.

What are the posterior probabilities for each proportion (θ) of the attack being against a specific target class given that 3 warheads were observed as being against city/industrial targets? From Bayes' Theorem, the following is calculated using equation 4.1. The posterior probability is found for each value of θ by multiplying the prior from Table 4.1 by the appropriate conditional from Table 4.2 and dividing by *the marginal* of **X**. The marginal of **X** is given as the following:

$$\text{marginal} = \sum_{i=0}^{15} [(x=3, y=12, \theta_i)\ P_0(\theta_i)]$$ where $P_0(\theta_i)$ is the prior probability of θ_i being the true state of nature.

$$\begin{aligned}
\text{marginal} = {} & (.0018)(0.0) + (.0018)(5.8915 \times 10^{-2}) + (.0018)(.1937) \\
& + (.0018)(.2501) + (.0018)(.2087) + (.0018)(.1299) \\
& + (.05)(6.339 \times 10^{-2}) + (.15)(2.449 \times 10^{-2}) \\
& + (.40)(7.364 \times 10^{-3}) + (.15)(1.649 \times 10^{-3}) \\
& + (.05)(2.537 \times 10^{-4}) + (.0018)(2.3206 \times 10^{-5}) \\
& + (.0018)(9.542 \times 10^{-7}) + (.0018)(9.348 \times 10^{-9}) \\
& + (.0018)(2.853 \times 10^{-12}) + (.0018)(0.0) = 1.176 \times 10^{-2}
\end{aligned}$$

Then

$$P(\theta = 0.0 | x=3, y = 12) = \frac{(.0018)(0.0)}{\text{marginal}} = 0.00$$

$$P(\theta = .0667 | x=3, y = 12) = \frac{(.0018)(5.8915 \times 10^{-2})}{\text{marginal}} = 9.174 \times 10^{-3}$$

$$P(\theta = .1333 | x=3, y = 12) = \frac{(.0018)(.1937)}{\text{marginal}} = 3.016 \times 10^{-2}$$

$$P(\theta = .2 | x=3, y = 12) = \frac{(.0018)(.2501)}{\text{marginal}} = 3.894 \times 10^{-2}$$

$$P(\theta = .2667 | x=3, y = 12) = \frac{(.0018)(2087)}{\text{marginal}} = 3.2497 \times 10^{-2}$$

$$P(\theta = .3333 | x=3, y = 12) = \frac{(.0018)(.1299)}{\text{marginal}} = 2.023 \times 10^{-2}$$

$$P(\theta = .4 | x=3, y = 12) = \frac{(.05)(6.339 \times 10^{-2})}{\text{marginal}} = 2.742 \times 10^{-1}$$

$$P(\theta = .4667 | x=3, y = 12) = \frac{(.15)(2.449 \times 10^{-2})}{\text{marginal}} = 3.178 \times 10^{-1}$$

$$P(\theta = .5333 | x=3, y = 12) = \frac{(.40)(7.364 \times 10^{-3})}{\text{marginal}} = 2.548 \times 10^{-1}$$

$$P(\theta = .6 | x=3, y = 12) = \frac{(.15)(1.649 \times 10^{-3})}{\text{marginal}} = 2.548 \times 10^{-2}$$

$$P(\theta = .6667 | x=3, y = 12) = \frac{(.05)(2.537 \times 10^{-4})}{\text{marginal}} = 1.0973 \times 10^{-3}$$

$$P(\theta = .7333 | x=3, y = 12) = \frac{(.0018)(2.3206 \times 10^{-5})}{\text{marginal}} = 3.613 \times 10^{-6}$$

$$P(\theta = .8 | x=3, y = 12) = \frac{(.0018)(9.542 \times 10^{-7})}{\text{marginal}} = 1.486 \times 10^{-7}$$

$$P(\theta = .8667 | x=3, y = 12) = \frac{(.0018)(9.348 \times 10^{-9})}{\text{marginal}} = 1.456 \times 10^{-9}$$

$$P(\theta = .9333 | x=3, y = 12) = \frac{(.0018)(2.853 \times 10^{-12})}{\text{marginal}} = 4.442 \times 10^{-13}$$

$$P(\theta = 1.0 | x=3, y = 12) = \frac{(.0018)(0.0)}{\text{marginal}} = 0.00$$

The resulting estimate of posterior probabilities is obtained for the data at time, t_{1}. This result will be interpreted as meaning that given the expected damage as measured by the sensors' predicted impact point and the damage model, there is a 0.0 probability that the intended attack consisted of no city/industrial targets, .009174 probability that it consisted of 1 intended city/industrial target, .03016 that it consisted of 2 city/industrial targets, .03894 that it consisted of 3 city/industrial targets,...0.00 that it consisted of all (15 out of 15) city/industrial targets. This result is an estimate at one point in time. Thirty seconds later a new estimate will be obtained. Eventually, at 6 minutes prior to impact, a point estimate can be found for the proportion of the attack which is against city/industrial targets.

The point estimate is given by the expected value of the posterior probabilities. The expected value is found by mulitplying each posterior probability times its proportion (θ) and taking the summation over all values of θ. Confidence intervals are constructed around the expected value by choosing those values of θ near the expected value such that when the posterior probabilities of the θ_is are summed the result is equal to or greater than the desired confidence level. The point estimates and confidence intervals for all of the classes of targets can be calculated and presented as shown in Table 3.1. Some sample output from the methodology is presented in Table 4.3.

The following example shows the calculation of the expected value for the output and the determination of the confidence interval.

$$E(p_i) = \sum_{i=0}^{15} [P(\theta_i|x,y)\, P_0\,(\theta_i)]$$

$$
\begin{aligned}
E(p_i) = {} & (0.00)(0.00) + (0.00)(0.0667) + (0.00)(0.1333) + (0.00)(0.2000) \\
& + (0.00)(0.2667) + (5.01E\text{-}28)(0.3333) + (1.65E\text{-}16)(0.4000) \\
& + (9.21E\text{-}9)(0.4667) + (2.08E\text{-}3)(0.5333) + (0.459)(0.6000) \\
& + (0.539)(0.6667) + (1.80E\text{-}4)(0.7333) + (5.64E\text{-}10)(0.8000) \\
& + (3.74E\text{-}21)(0.8667) + (0.00)(0.9333) + (0.00)(1.000)
\end{aligned}
$$

$$E(p_i) = 0.636$$

TABLE 4.3 Sample Posteriors

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL AT 6 MINUTES

θ	**Posterior Probability**
0.0000000E+00	0.0000000E+00
6.6670001E-02	0.0000000E+00
0.1333300	0.0000000E+00
0.2000000	0.0000000E+00
0.2666700	0.0000000E+00
0.3333333	5.0085753E-28
0.4000000	1.6473281E-16
0.4666700	9.2067349E-09
0.5333300	2.0839891E-03
0.6000000	0.4588318
0.6666700	0.5389044
0.7333300	1.7975054E-04
0.8000000	5.6429178E-10
0.8666700	3.7375663E-21
0.9333300	0.0000000E+00
1.000000	0.0000000E+00

The confidence interval around this expected value is found by summing the posterior probabilities of the θ_i around 0.636 until the desired confidence level is reached (0.90 for this research). For the example presented here, this confidence level is reached by summing the posterior probabilities for $\theta = 0.6000$ and $\theta = 0.6667$ found in Table 4.3. The sum of these two posterior probabilities yields 0.9977 which accounts for most of the probability for θ. The resulting confidence intervals for all of the target classes are shown in Table 4.4.

TABLE 4.4 Expected Value and Confidence Intervals

AT 6 MINUTES PRIOR TO IMPACT THE FOLLOWING TABLE OF RESULTS EXIST: (90% CONFIDENCE LEVEL)

****

Class	Lower Bound (θ)	Expected Value (θ)	Expected Value (X)	Upper Bound (θ)
1 CITY INDUSTRIAL	0.600	0.636	9	0.667
2 OTHER MILITARY	0.200	0.204	3	0.204
3 STRATEGIC MILITARY	0.067	0.067	1	0.067
4 CRITICAL CCC	0.132	0.132	2	0.133

These estimates will have a very small variance if the distribution of the targets are such that there is very little misclassification occurring. However, as mentioned earlier, if two or more targets are very close together, the technique of choosing the target simply with the greatest amount of damage as the intended target will inflate the perceived confidence in the estimate. In other words, the actual probability of misclassifying a warhead may be higher than indicated by the results meaning that the MOE is slightly lower than the reported value.

Another problem with the estimates of θ for the four target classes as presented in Table 4.4 is that the values of θ are not independent among the four classes. By treating the process as binomial and measuring the sample as a combination of **X**, the number of warheads attacking targets from the class of interest and **Y** all other warheads, the estimates of θ end up being slightly higher than they are in reality. This fact is illustrated by examining the expected values of θ in Table 4.4 across the four class of targets. The sum of the expected values of θ is 1.039 which is of course impossible. The expected values of θ should sum to 1.000.

The difference between the results and expected values of θ is caused by the dependence among the values of θ among the four classes. Actually three of the values of θ are independent and the fourth is determined. This problem could be alleviated by treating the process as a multinomial or by finding the correlation among the values of θ. In either case the results will not change the expected values by much. In all the runs attemped (approximately 60), the sum of the values of θ across the four target classes never exceeded 1.05. This result implies the dependence among the four target classes is small. Even with this slight dependence, the actual expected values of θ will always be within the reported confidence intervals and the expected value of **X** will never change. For these reasons, refining the calculation of the expected values of θ was left as an objective for future research. However, there are problems with the methodology that do need to be dealt with in this research effort.

Potential Problems with the Methodology. This possibility of getting a higher percentage of targets correctly classified than appropriate for the data needs to be examined further. Review for a moment the methodology as proposed. The radar sensors measure the position of the reentry vehicle with some uncertainty and from this measured position the predicted impact points are calculated. These impact points are therefore estimates of where the warhead will detonate in an area. The methodology then takes these predicted impact points and calculates the damage to every target in the area based on a nuclear effects and damage expectancy model. The estimates of damage to all of the targets in the data base are compared and sorted for the largest value of probability of damage. The proposed methodology then selects this target and the associated target class as the intended target class of the warhead. This procedure is repeated for all fifteen warheads in the attack. The numbers of warheads "assigned" to each target class are summed and used by the Bayesian processor portion of the methodology to estimate the proportion of the attack which is intended against each target class. On the surface this approach seems sound but a potentially critical problem exists with the methodology.

Implicit in the methodology is the assumption that the target receiving the most damage is the intended target of the warhead. This assumption then leads to the assumption that the estimated "intended" target is a member of the "intended" target class. But consider what might happen if the radar information was inaccurate to the degree that the predicted impact point fell near a target that was in the area but was not the intended target. In other words, the intended target and target class of the warhead was actually some other target and target class in the area.

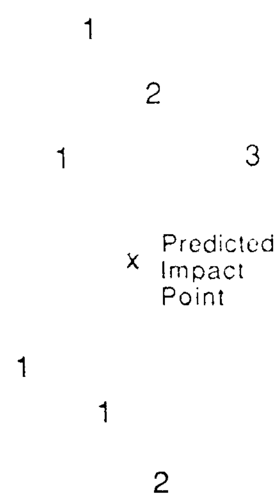

Figure 4.2 Intended Target Uncertainty

Figure 4.2 illustrates the uncertainty which could be present. The shaded area represents the area of uncertainty due the inaccuracy of the radar. The numerals 1, 2, and 3 represent targets from those respective target classes. The predicted impact point occurs at the centroid of the ellipse but in actuality, the warhead could land any where in the shaded area. Which target in the area is the intended target? In reality it could be any of the targets with nearly equal probability. What would a warhead predicted to land in an area such as the one in Figure 4.2 imply about intent when compared to one landing in an area as shown in 4.3?

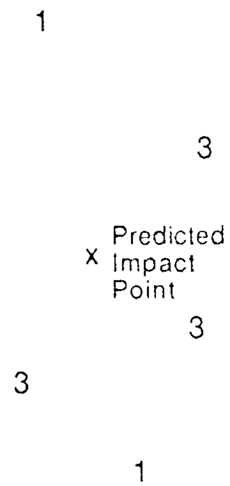

Figure 4.3 Uncertainty with Implications

In Figure 4.3, the intended target would appear to be one of the targets belonging to Class 3, strategic military targets. The targets from class 1, cities, will receive collateral damage which may be significant but they were probably not the intended targets. The current algorithm would classify the warhead as being intended for a class 1 target in Figure 4.2 and a class 3 target in Figure 4.3 but no allowance is made for the possibility that the intended target in both situations might have been a class 3 target. This potentially misleading information is then used by the Bayesian processor in the methodolgy. Now consider how Bayes' Theorem is traditionally applied.

Bayes' Theorem as applied in a traditional sense assumes pefect sampling information. Consider the classical "balls in an urn" problem. In that problem, an urn is known to contain a mixture of green and red balls and it is also known that the balls can only exist in a finite number of proportions to one another [31: 15]. For the sake of example assume there are fifty balls total and that there are four possible mixtures, 10 green and 40 red, 20 green and 30 red, 25 green and 25 red, or 40 green and 10 red. Now consider how Bayes' Theorem is applied to determine the actual mixture of balls in the urn. Samples are drawn from the urn and used to update the prior probabilities of each mixture of balls occurring. If a sample of five balls are drawn which contains 4 green balls and 1 red ball, then the resulting probabilities obtained after applying Bayes' Theorem will be shifted toward the mixture of 40 green and 10 red balls. This procedure works because based on the sample, the person estimating the "true" mixture of balls in the urn feels that the urn probably contains more green balls than red balls. This belief in the mixture of balls in the urn would become stronger if over time several samples were drawn with each sample containing more green balls than red ones. In this example, the person sampling the balls from the urn had total confidence in his sampled information because he could easily tell if he had drawn a green ball or a red ball from the urn. But what would be the effect on the results if the color of some of the balls were unknown even **after** they were drawn.

The effect of uncertainty in the color of the sampled balls should be to lower the confidence in the sampled information and consequently one should not be so willing to modify prior probabilities about the state of nature being tested. Unfortunately, Bayes' Theorem as applied in the research problem does not consider the confidence of the information therefore all information used in the methodology is assumed to be perfectly known. This assumption of perfect information may lead to erroneous results if the uncertainty of the radar is too large. A method to correct for this condition might be to find a technique which would modify the prior probabilities when the confidence in the sampled information was high and to not modify or modify very little the priors when the confidence in the sampled information was low. This potential problem with using Bayes'

Theorem as proposed in the solution methodology will be explored further if the information obtained in the samples is too uncertain.

This example and discussion of potential problems with using Bayes' Theorem concludes the discussion of the theoretical basis for using Bayesian analysis as the solution methodology. The next section will present documented applications of Bayesian analysis in a similar environment.

Documented Application. A supporting study was found which discusses at length the use of Bayesian analysis and statistics in aiding human information processing and decision making. The specific application was for a threat evaluation system which attempted to maintain surveillance over a ground area from which an enemy threat might originate. The system was called PIP for Probabilistic Information Precessing. Figure 4.4 presents a graphic display of the system. The system uses a number of different technical sensors and the display from the sensors is presented to a group of probability estimators. Appropriate inputs were made to PIP and the actual data processing consisted of repeated applications of Bayes' Theorem. PIP, as is proposed in the methodology for this research, also used the outputs of one set of calculations as the prior probabilities for the next set of calculations. The conditional probabilites were calculated from sensor accuracy in the case of PIP whereas in the research methodology proposed they are the result of sensor measurement and application of the binomial distribution. In that system, the probability estimators were people.

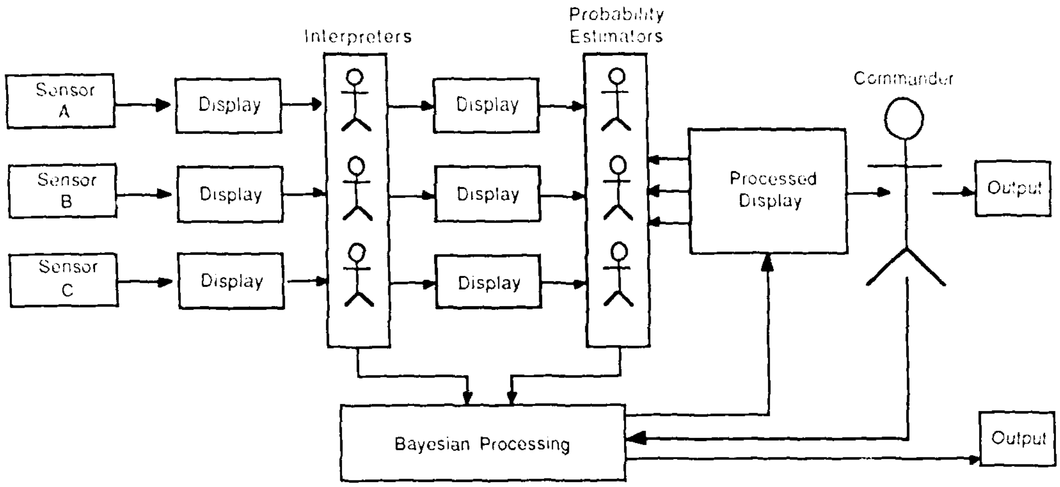

Figure 4.4 PIP for Threat Evaluation [16: 70]

In the system at NORAD the probability estimators would be a digital computer. The function of the Bayesian processor was to generate distribution functions. These functions were used by the human decision maker to make a better decision than could be made with deterministic methods. This conclusion seemed to be the theme of the study, that a better decision could be made using a system with Bayesian processing than without [16: 68-71]. This study, although slighly out of date, adds validity to the proposed methodology for solving the problem of determining intent.

A more recent study which documents the applicability for using Bayesian analysis to solve this type of problem is one being conducted by the U.S. Army Strategic Defense Command. That study concerns the building of the Attack Assessment Decision Aid which has as one of its goals, the assessing of which specific U.S. targets are under attack and then a characterization of the attack. The decision aid uses input data from sensors with a high-level Bayesian inference system to determine the high-level attack characteristics [17: 1,2]. This particular decision aid has incorporated artificial intelligence (the use of a

Bayesian inferencing algorithm) to present the user with a picture of what is happening. The U.S. Army research stops short of processing the radar data and predicted impact points as furthered by the research presented here.

Future Application. The data which could be displayed as shown in Table 3.1 must still be interpreted by CINC NORAD and his advisors. The human element ultimately will decide if the U.S. is under attack and what class or classes of targets are the intent of the attack. The proposed methodology has simply allowed the necessary data for making those decisions to be put in a format which can more easily be interpreted. As cited in the study on PIP, the end result is that the decision maker will make a better determination of Soviet intent than he can now with little or no intent determination capability.

Bayesian analysis allows the decision maker to influence the outcome by using his subjective probabilities of what he thinks will happen as prior probabilities to combine with conditional probabilities based on observed information. The next section of this chapter specifies the test hypotheses and conditions which will be used to meet each sub-objective. This essentially will be the experimental design for the research.

Experimental Design

Since the primary objective of the research is to find the sensor accuracy necessary to generate specified confidence levels of attack estimates, an iterative approach will be used. The starting conditions of the model will be determined and a set of data will be obtained and analyzed. The data will be evaluated for its confidence value level by using the measure of effectiveness. Then for each confidence level, the parameters of the models will be varied in a systematic way until the target confidence level is reached. This will be the general approach used to meet all the sub-objectives which support the main research objective. The next few sections discuss the test hypotheses and conditions associated with meeting the overall objective and each sub-objective.

Test Hypotheses and Conditions. The primary objective of the research is to investigate radar sensor accuracies to determine if a threshold exists which would give a 75, 90, and 98% level of correctly-classified targets in an attack characterization. As previously mentioned, this objective will be met by conducting experimentation using an iterative approach. The present level of attack characterization accuracy will be obtained using current radar systems capabilities. The level of attack characterization accuracy will be evaluated by using the measure of effectiveness which is the complement of the classification error rate. The correctly-classifed rate is found by using a confusion matrix such as the one shown in Table 3.2.

The desired correctly-classified levels identified in the sub-objectives will be met by improving the radar accuracies and evaluating the results. Table 4.5 presents the current radar accuracy of the attack warning and characterization system.

TABLE 4.5 Current Radar Accuracies
(one-sigma values)

PARAMETER	ACCURACY
X	25.0 meters
Y	25.0 meters
Z	25.0 meters
V_x	15.0 meters/sec
V_y	5.0 meters/sec
V_z	15.0 meters/sec

The parameters will be considered to act independently although this might not be completely valid under all situations. Treating the parameters as though they do act indepently is a simplifying assumption which is also made by personnel at Foreign Technology Division who use the Trajectory Simulation Program [28]. Also, a consistent change will be made to each parameter although in actuality, an entire spectrum of values would exist for each parameter which would yield the same level of confidence in the attack characterization data. First before doing any parameter varying, the accuracy of the attack characterization will be determined using "perfect information" to determine if the desired correctly classified levels can be attained. The first change will be 5 meters in X, Y, and Z and 5.0 meters/sec for V_x and V_z. The change in V_y will be 1 meter/sec. This procedure will be continued until the correctly-classified level is reached or the upper bound on accuracy is reached, that of having "perfect" information.

The next sub-objective is to analyze missile accuracy (CEP) and determine how it affects attack characterization. This objective will be met by varying the missile CEPs used in the trajectory simulation program and the damage expectancy model. The effect if any on the attack characterization data will be reported with a plot of CEP versus attack characterization accuracy.

The final sub-objective is to determine the longest time before first warhead detonation at which attack characterization could be determined at the 98% confidence level. This objective is tested using the most accurate missile warning system possible. This situation essentially is testing the system under almost "perfect" information.

Purpose of Objectives. There is a fundamental purpose for each sub-objective beyond the explicit stated objective. That purpose will be presented in this section for each of the sub-objectives. The first sub-objective is developing a measure of effectiveness which is used to evaluate the results. Part of the problem in the area of intent determination is recognizing when the Soviet's intent had been determined. Using the correctly classified rate as the measure of effectiveness is a good empirical method for determining how any classification routine is performing.

The next sub-objective is fundamentally satisfying the purpose of the research. The original question posed by Lt. Col. Lawhern was to find the sensor accuracy necessary to yield specifed levels of confidence of intent determination. The second sub-objective is to find the sensor accuracy needed to enable the missile warning system to provide attack characterization at the 75, 90, and 98% confidence levels.

The third sub-objective is to evaluate the effect of CEP on attack characterization. This objective will give the U.S. decision makers a feel for the sensitivity of the estimates it makes concerning Soviet missile accuracy. The estimate of 300 meters CEP for the SS-18 and SS-19 may be too small or the Soviets may improve beyond this point. Knowing how attack characterization would be affected as the result of a change in Soviet CEPs could be very useful.

Finally, the last sub-objective is to find the longest time before warhead detonation at which the confidence level of the attack characterization would be extremely accurate. The purpose of this objective is to determine if a very reliable decision concerning Soviet intent can be made significantly before the 6 minute point before impact. This result could buy the U.S. leaders more decision time. There is a trade-off between waiting longer to get a better estimate of intent and having less time to make a decision and react once that intent is determined.

The next chapter will present the results of the experimentation and the analysis of those results. Each sub-objective will be analyzed closely to determine the full implications of the research. Sensitivity analysis will be conducted on key variables. Then the results and analysis in chapter V will lead directly into the conclusions and recommendations of chapter VI.

V. Findings and Analysis

Overview

This chapter contains all of the findings and results of the experimentation and the research. The findings and results are analyzed with respect to what was obtained and how it was obtained. As will be shortly seen, undesirable results were obtained when the radar accuracy was set at its most inaccurate level. The experiments with the most inaccurate radar simulates the current state-of-the-art. When the accuracy of the radar was improved, the methodology performed as planned. The bottom line result is that Bayesian analysis as implemented here did not prove to be a robust way of determining the intent of a limited nuclear attack.

Preliminary Analysis

Before applying the methodology to the experimental design, some preliminary analysis of the methodology was accomplished. This analysis was done to ensure the methodology was performing correctly and that the results were consistent with *a priori* expectations. The preliminary test cases were a baseline case using current state-of-the-art radar accuracy, a case where the radar has been improved to a level several times more accurate than the current level, and the case where there is perfect information available meaning that all of the uncertainty from the radar has been removed and the only uncertainty remaining is from missile CEP. The results obtained from applying the methodology to each of these test cases will be presented and analyzed for significance.

Baseline Case. The baseline case is when the radar accuracy parameters are set at their current state-of-the-art levels. These settings are presented in Table 5.1.

TABLE 5.1 Current Radar Accuracies
(one-sigma values)

PARAMETER	ACCURACY
X	25.0 meters
Y	25.0 meters
Z	25.0 meters
V_x	15.0 meters/sec
V_y	5.0 meters/sec
V_z	15.0 meters/sec

These values of radar accuracy are only approximate values since the actual values are classified. The values were obtained through discussions with missile warning experts [30], personnel at Foreign Technology Division [28], and from *Janes's Weapon Systems* [23]. These values are dependent on the angle between the object being tracked and the radar site viewing the object. In this sense therefore, the tracking accuracy is dependent on which radar site is viewing the object [28]. For all of the results presented in this research, the radar site viewing the object will be taken as the one which minimizes the overall tracking error.

The values in Table 5.1 represent the one-sigma error in the six parameters necessary to position a reentry vehicle in space and propogate its motion to impact. A Monte Carlo process was used to add error in the six parameter state vector for each reentry vehicle at 30 second increments. After the noise was added to the state vector, the reentry vehicle's trajectory was calculated using a trajectory simulation program ana an impact point was obtained.

The simulated attack for the preliminary analysis will be a uniform attack, one which is *not oriented toward any one particular class of targets.* The data for the simulated attack is contained in Appendix I. The character of the attack and the intended targets are presented in Table 5.2.

TABLE 5.2 Preliminary Results Attack

RV Number	Target	Target Class
1	McClellan Air Force Base	2
2	March AFB, 15th AF, GWEN station	4
3	Los Angeles, California	1
4	Beale Air Force Base, Tanker Wing	3
5	Castle Air Force Base	3
6	Tustin Marine Corps Air Station	2
7	U.S. Naval Air Station North Island	2
8	Beale AFB, PAVE PAWS radar, GWEN	4
9	George AFB	2
10	Anaheim, California	1
11	Norton AFB, Ballistic Missile Office	3
12	Cerritos, California	1
13	Glendale, California	1
14	Vallejo, California	1
15	Davis, Early Warining Radar site	4

This simulated attack was generated using SIMATTACK.SLAM whose source code is in Appendix E. Even though a uniform attack was designated, an apparent non-uniform attack was obtained. A totally uniform attack would have consisted of 56.1% class 1 targets, 23.7% class 2 targets, and 10.1% class 3 and class 4 targets. These percentages are derived from dividing the number of targets of each class by the total number of targets in the data base (148 targets). For example, there are fifteen critical command and control, or communications targets in the area of interest. A totally uniform attack would be one which targeted critical command and control, or communications targets with 15/148 or 10.1% of the warheads. The remaining warheads would be used to attack the other classes of targets according to their proportion of the total population. Given a random attack, the expected value of targets from each class would have been approximately eight class 1, three class 2, and two class 3 and class 4 targets. The mix of the attack obtained from the simulated attack program consisted of five class 1, four class 2, and three class 3 and class 4 targets. These expected results and realized results are summarized in Table 5.3.

TABLE 5.3 Simulated Attack Character

Target Class	Expected Results	Obtained Results
1 City/Industrial	8	5
2 Other military	3	4
3 Strategic military	2	3
4 Critical CCC	2	3

Since these results were unexpected, a larger sample size of attacking warheads was generated. When fifty warheads were generated, the obtained results matched very closely with the expected results. It is apparent that the unexpected attack mix is caused by the small sample size. The sample represents only 10% of the available targets. Obtaining the numbers of targets in each class is not abnormal given the small sample size. Therefore, the research proceeded with the simulated attack contained in Table 5.2. Using an attack which contained a different number of intended targets than one would expect from the class proportions in the population turned out to be fortuitous.

Because the attack was different than one would expect in a random sample, the answer generated by the methodology under the greatest radar uncertainty exposed a serious flaw in the methodology. Table 5.4 contains the results obtained from the baseline radar accuracy. The data was generated using a program written in FORTRAN which calculates posterior probabilities using Bayes' Theorem. The results are used to find an expected value and a confidence interval around θ, the proportion of warheads attacking each specific class. The source code for this program, CHARATTACK.F, is presented in Appendix J. All of the results are calculated by using the data taken from first detection down to 6 minutes prior to impact. For a given setting of radar parameters, 6 minutes prior to impact represents the point where the radar should be the most accurate before a decision has to made by CINC NORAD and the NCA. The table presents the expected value of the proportion of the attack which is intended for each target class. The lower and upper bound represent the confidence interval around the point estimate of θ, the proportion of the attack which is intended against a specific target class.

TABLE 5.4 Baseline Case Results

AT 6 MINUTES PRIOR TO IMPACT THE FOLLOWING TABLE OF RESULTS EXIST: (90% CONFIDENCE LEVEL)

****

Class	Lower Bound (θ)	Expected Value (θ)	Expected Value (X)	Upper Bound (θ)
1 CITY INDUSTRIAL	0.600	0.636	9	0.667
2 OTHER MILITARY	0.200	0.204	3	0.267
3 STRATEGIC MILITARY	0.067	0.067	1	0.067
4 CRITICAL CCC	0.067	0.132	2	0.133

On this surface the results in Table 5.4 appear consistent and desirable because they converge to a tight interval. But the expected value of **X** exposes a problem with the methodology. Table 5.3 contains the values for the intended numbers of targets in each class. The methodology has only correctly predicted 73.3% of the targets. Table 5.3 also contains the expected value of targets given a uniform attack against all target classes. Notice that the obtained results in Table 5.5 agrees very closely with the expected value in Table 5.3. The meaning of this is that the methodology has converged to the expected value of each target class under a uniform attack **not** the number of targets in each class which were actually intended in the attack. This result is very unsettling. Tables 5.5a, 5.5b, 5.5c, and 5.5d illustrate even a bigger problem with the methodology. These tables contain the posterior distributions of θ for each class of targets. Notice where the majority of the probability is located. For city industrial targets, the posterior distributions found in Table 5.5a converge to a tight confidence interval as desired but to the **wrong** answer.

TABLE 5.5a Posteriors for Class 1, Baseline Case

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL AT 6 MINUTES

θ	Posterior Probability
0.0000000E+00	0.0000000E+00
6.6670001E-02	0.0000000E+00
0.1333300	0.0000000E+00
0.2000000	0.0000000E+00
0.2666700	0.0000000E+00
0.3333333	5.0085753E-28
0.4000000	1.6473281E-16
0.4666700	9.2067349E-09
0.5333300	2.0839891E-03
0.6000000	0.4588318
0.6666700	0.5389044
0.7333300	1.7975054E-04
0.8000000	5.6429178E-10
0.8666700	3.7375663E-21
0.9333300	0.0000000E+00
1.000000	0.0000000E+00

Using the methodolgy as presented, a decision maker would incorrectly determine that the attack was intended mostly against city industrial targets (9 or 10 targets attacked). From the results in Table 5.3, one can see that this is not the case. With most of the probability allocated to θ values of 0.600 and 0.667 the methodology has produced a misleading answer. The actual value of θ is 0.33333 because the intended attack is five city/industrial targets out of fifteen attacking warheads. The calculated posterior probability for θ = 0.33333 found by applying the methodology is 5.009E-28. This number is extremely low and is not at all near the actual value. Tables 5.5b, 5.5c, and 5.5d for the other target classes yield the same misleading results.

TABLE 5.5b Posteriors for Class 2, Baseline Case

THE NEW DISTRIBUTION FOR OTHER MILITARY AT 6 MINUTES

θ	**Posterior Probability**
0.0000000E+00	0.0000000E+00
6.6670001E-02	8.9345815E-14
0.1333300	2.7347263E-03
0.2000000	0.9339560
0.2666700	6.3294642E-02
0.3333300	1.4610840E-05
0.4000000	3.1256414E-11
0.4666700	7.6542150E-19
0.5333300	1.5856621E-28
0.6000000	0.0000000E+00
0.6666700	0.0000000E+00
0.7333300	0.0000000E+00
0.8000000	0.0000000E+00
0.8666700	0.0000000E+00
0.9333300	0.0000000E+00
1.000000	0.0000000E+00

As shown in Table 5.5b, the methodology has converged to a θ value of 0.200 which is equivalent to 3 warheads out of 15 being intended for other military targets. From the data in Table 5.3, one can see the problem. The actual number of warheads attacking class 2 targets is four. The methodology should have converged to a θ value of 0.26667. Instead, the methodology reports the value of θ = 0.266667 as 0.0633. This result would lead a decision maker to assuming that less warheads had been assigned against class 2 targets than actually intended. A decision maker basing U.S. response from this result could select an inappropirate response for the actual intent of the attack.

Another misleading aspect of the data is the small variance of the probability around θ = 0.2000. Inspecting the data, one would assume that because of the small variance, there is very little uncertainty attached to the observations. As will be explained much more thoroughly later, this assumption is not valid.

TABLE 5.5c Posteriors for Class 3, Baseline Case

THE NEW DISTRIBUTION FOR STRATEGIC MILITARY AT 6 MINUTES

θ	Posterior Probability
0.0000000E+00	0.0000000E+00
6.6670001E-02	0.9999997
0.1333300	3.1168523E-07
0.2000000	1.8748579E-15
0.2666700	6.3758692E-25
0.3333300	1.3035275E-35
0.4000000	0.0000000E+00
0.4666700	0.0000000E+00
0.5333300	0.0000000E+00
0.6000000	0.0000000E+00
0.6666700	0.0000000E+00
0.7333300	0.0000000E+00
0.8000000	0.0000000E+00
0.8666700	0.0000000E+00
0.9333300	0.0000000E+00
1.000000	0.0000000E+00

For the strategic targets, class 3, the methodology has converged to a θ of 0.0667 which corresponds to 1 warhead out of 15 as being intended for the class. Results from Table 5.3 contradict this result. The attack actually intended three out of the fifteen warheads to be against strategic military targets. The methodology calculates the posterior probability of $\theta = 0.2000$ as 1.87E-15 which is essentially zero. Once again, the methodology has failed to correctly characterize the attack. Finally, as shown in Table 5.5d, the methodology also converges to the wrong answer for Class 4, critical command, control, or communications targets.

AD-A185 249 A METHODOLOGY FOR DETERMINING THE INTENT OF A LIMITED NUCLEAR ATTACK(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING 2/3

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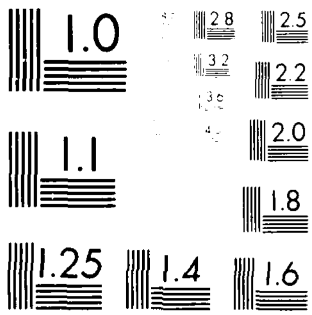

MICROCOPY RESOLUTION TEST CHART

TABLE 5.5d Posteriors for Class 4, Baseline Case

THE NEW DISTRIBUTION FOR
CRITICAL COMMAND, CONTROL, OR COMMUNICATIONS AT 6 MINUTES

θ	**Posterior Probability**
0.0000000E+00	0.0000000E+00
6.6670001E-02	1.4786120E-02
0.1333300	0.9841074
0.2000000	1.1064765E-03
0.2666700	4.4043360E-09
0.3333300	2.5803636E-16
0.4000000	3.1143526E-25
0.4666700	6.4803201E-36
0.5333300	0.0000000E+00
0.6000000	0.0000000E+00
0.6666700	0.0000000E+00
0.7333300	0.0000000E+00
0.8000000	0.0000000E+00
0.8666700	0.0000000E+00
0.9333300	0.0000000E+00
1.000000	0.0000000E+00

As can be observed from the data presented in Tables 5.5a, 5.5b, 5.5c, and 5.5d, the methodology has not converged to the correct answer. This result must be examined further. However, before examining the problem with the methodology under the baseline case, the results for the other two cases will be presented. It will be seen that when the radar is improved, the methodology performs as desired and converges to a correct answer with a high percentage of targets being correctly classified. The better the accuracy of the radar, the higher percentage of targets that are correctly classified by the methodology.

Improved Radar Case. When the radar is improved to a higer degree of accuracy, the methodology performs as expected. It was felt at this point that if the methodology could converge to a correct answer with improved radar data, then the method was still a valid approach for solving the problem. The radar was improved to a level such that the error introduced by the radar was only 20% of the unimproved radar error. The values for the parameters of the radar are presented in Table 5.6.

TABLE 5.6 Improved Radar Accuracies
(one-sigma values)

PARAMETER	ACCURACY
X	5.0 meters
Y	5.0 meters
Z	5.0 meters
V_x	3.0 meters/sec
V_y	1.0 meters/sec
V_z	3.0 meters/sec

The results obtained by the methodology when the radar was improved to the levels shown in Table 5.6 are contained in Table 5.7. It can be seen that the methodology has produced a reasonable answer given the mix of the attack. The random set of targets which were drawn from the target data base contains a few targets which are very close to one another. From Table 5.1, *it can be seen that both the* tanker wing and the radar site at Beale Air Force Base are under attack. Also, Tustin Marine Corps Air Station and Anaheim California are very close to one another. With these particular sets of targets, it will be difficult for any methodology to properly classify all of the warheads in the attack.

TABLE 5.7 Improved Radar Case Results

AT 6 MINUTES PRIOR TO IMPACT THE FOLLOWING TABLE OF RESULTS EXIST: (90% CONFIDENCE LEVEL)

****

Class	Lower Bound (θ)	Expected Value (θ)	Expected Value (X)	Upper Bound (θ)
1 CITY INDUSTRIAL	0.400	0.459	7	0.467
2 OTHER MILITARY	0.267	0.272	4	0.333
3 STRATEGIC MILITARY	0.067	0.071	1	0.133
4 CRITICAL CCC	0.200	0.202	3	0.267

The improved radar has an MOE (% warheads correctly classified) of 0.86667 which is reasonably good. A closer look at the data reveals that since the actual attack is 5,4,3,3 (intended number of targets for Class 1, Class 2, Class 3, Class 4) that two of the strategic military targets are probably being misclassifed as city/industrial targets. This condition would lower the MOE to 86.7% because there are two misclassifications occurring.

A sample of the posterior probabilities for the improved radar is contained in Appendix K. The data presented in Appendix K is only for 15 minutes prior to impact, 10 minutes prior to impact, 8 minutes prior to impact, and finally down to the cut-off time, 6 minutes prior to impact. This set of data illustrates how the MOE improves over time and how the posterior probabilities converge to the correct answer. This data seems to validate the method as appropriate. The only issue at this point is how the probabilities should be updated when there is a high degree of uncertainty in the radar data. This issue will be thoroughly discussed after the remaining preliminary results are presented.

Perfect Radar Information Case. Under this level of experimentation, all of the uncertainty in attack characterization due to error in the radar has been removed. The only uncertainty in the location of the impact points is due to missile CEP. As expected, the methodology performs very well under the perfect information condition. Table 5.8 contains the results for this preliminary analysis.

TABLE 5.8 Perfect Radar Information Results

AT 6 MINUTES PRIOR TO IMPACT THE FOLLOWING TABLE OF RESULTS EXIST: (90% CONFIDENCE LEVEL)

****

Class	Lower Bound (θ)	Expected Value (θ)	Expected Value (X)	Upper Bound (θ)
1 CITY INDUSTRIAL	0.333	0.380	5	0.400
2 OTHER MILITARY	0.267	0.267	4	0.267
3 STRATEGIC MILITARY	0.133	0.133	2	0.133
4 CRITICAL CCC	0.267	0.267	4	0.267

The methodology correctly classifies 93.3% of the warheads under the perfect radar information condition. From Table 5.8 it can be seen that the only misclassification is when one of the warheads which is really a target class 3 warhead is classified as a target class 4 warhead. The data illustrating the convergence of the posterior probabilities to a θ value is presented in Appendix L. Once again, the data for several points in time have been included in the appendix to show how the MOE is improving over time and how the probability distribution of θ is converging to the actual value. The next section of this chapter will explore the reasons why the methodology is not robust enough to handle the current radar accuracy condition. Alternatives to the way Bayes' Theorem is applied will be presented to illustrate the work that needs to be accomplished before a robust methodology is found which can accurately determine the intent of a limited nuclear attack.

Reasons for Methodology Failure

As discovered during the preliminary analysis, the methodology fails to converge to the correct answer when there is a large amount of inaccuracy in the radar. The reason for this failure was previewed in chapter IV. The sampled data which is received by the Bayesian processor is assumed to be certain. There is no lack of confidence in this data so it is accepted as the truth and the prior probabilities are modified accordingly. However, as discussed in chapter IV, the sampled data is uncertain, it cannot capture the true intended targets in all circumstances. In assuming the intended target to be the one which receives the most damage in an area surrounding the detonation of the warhead, many complexities are ignored. For instance, consider the two impact areas containing targets as shown in Figure 5.1. Would one expect the same amount of information from both samples or would one put more confidence in the area which only contains one class of targets?

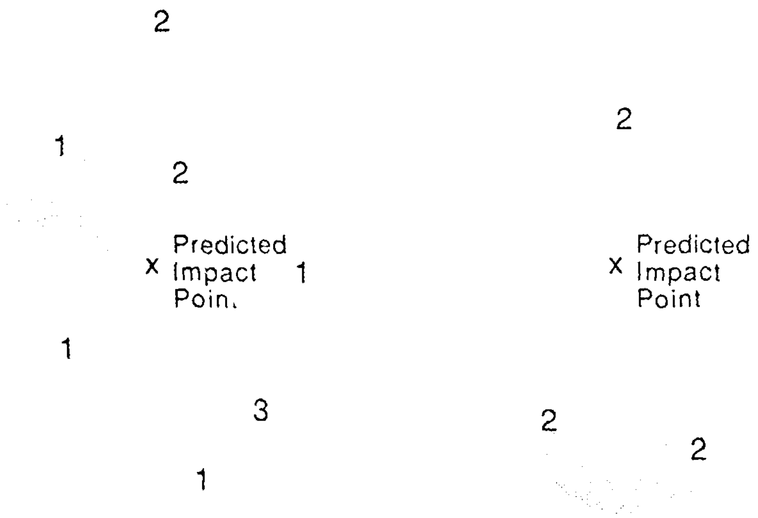

Figure 5.1 Confidence Dichotomy

The methodology as currently applied would not make a distinction between these two cases yet there clearly is a difference. A person should not be willing to modify his priors if the area of uncertainty on the left in Figure 5.1 is obtained and he believes that the true attack is weighted heavily toward class 3 targets. Actually with a large amount of uncertainty, a person should be very careful as to how much he modifies the priors. When little uncertainty exists such as in the case of the impact area on the right in Figure 5.1, then the priors should be modified by the appropriate amount based on the new information. What is needed is a technique to capture this desired property. In the next few sections, three techniques are discussed which could capture the desired characteristics of a good Bayesian processor.

Using Damage Density Functions. The first of these techniques attempts to find a method for calculating conditional probabilities such that the ratio of conditional probability to marginal probability is close to one when the confidence in the information is low and a ratio different than one when the confidence in the information is high. This situation would allow the priors to be modified only when appropriate to do so. The needed situation is really Bayes' Theorem as depicted in equation 5.1

$$P(\theta_i|x,y,\phi_t) = \frac{P(\theta_i)\,P(x,y|\theta_i,\phi_t)}{P(x,y)} \qquad [5.1]$$

where ϕ_t is a function which represents the confidence of the information received by the radar. The function is dependent on time because the information becomes more accurate over time hence ϕ is subscripted with a t.

Bayes' Theorem can be thought of as a means for modifying prior probabilities with a weighting function dependent on an observed sample. This weighting is simply the conditional probability of **X** being observed given a true proportion θ divided by the marginal probability of **X** occurring. Equation 5.2 illustrates this weighting.

$$P(\theta_i|x,y,\phi_t) = P(\theta_i)\, w_i \qquad [5.2]$$

where: $$w_i = \frac{P(x,y|\theta_i,\phi_t)}{P(x,y)}$$

Several methods were investigated in an attempt to find conditional probabilities that are close to the marginal probability when the confidence in the information is low. Having values of the conditional and marginal probabilities close to each other would make their ratio near unity thus the priors would be modified only slightly. When the confidence in the information is high, then the ratio of conditional to marginal probabilities should be significantly different than one so that the priors can be appropriately modified. It proved to be very difficult to find a method for computing conditional probabilities which displayed the necessary properties. Part of the problem is that the conditional probabilities are not discrete although they have been treated as though they are in the proposed methodology of this research. Since the conditional probability is a function of ϕ which improves over time, there is a continuous range of radar accuracies and impact area situations that exist. These confounding effects make the solution to the conditional probabilities non-trivial.

The probability of observing a sample **X** is dependent on **both** the intended proportion of the attack, θ, and the circumstances of the impact point. If the observation is late in the object's flight when the radar information is better, then the area where the warhead could detonate is smaller. A smaller area under normal conditions means that fewer targets will be considered at risk. This fact means that the information about the damage each target is receiving is probably a better estimate of reality. Under this condition, the confidence in the data should be higher therefore, the conditional probability should significantly influence the prior probabilities.

If the observation is taken early upon detection, such as at 900 seconds (15 minutes prior to impact) then the area of uncertainty will be quite large. This larger area will most likely contain more targets with one of them probably being the intended target. In this situation, the confidence in the estimate of damage to each target is quite low and consequently the priors should not be modified by any significant amount.

A heuristic technique which might display the necessary properties is to use the probability density functions for the expected damage of each target in the area of uncertainty. These density functions of the expected damage are illustrated in Figures 5.2 and 5.3. For the specific examples shown, the probability density functions for the expected damage are plotted parallel to the longitudinal axis of the impact areas. Note that the shape of the density function is different for each class of targets. The reason for this difference in shape is that each class of targets has a different response to the same level of nuclear effects. The height of the damage density functions depend on the likelihood that the target is the intended target given its position relative to the predicted impact point. A large total area of the expected damage density function for a target implies that there is a strong likelihood that the target is the intended target based on its distance and position relative to the predicted impact point. As the predicted impact point moves away from a target location, the likelihood that the target is the intended target decreases. This condition would be reflected by a decrease in the total size of the expected damage density function.

A weighting function might be developed from the relative proportion of the damage to each class of targets which are contained in the damage area of the warhead. The damage to each class would be the sum of all the damages, measured by the expected damage density functions, for each target which is of that specific class. Figure 5.2 illustrates the idea. As shown in Figure 5.2, the relative density of target class 1 would be higher than the others because there are more targets in the area. Without any better information, the attack would seem to be against one of the class 1 targets even though a class 3 target is closest. Even this technique ignores the possibility that the intended target might really be the class 4 target and the radar has simply because of its inaccuracy, failed to predict the impact point close to the intended target. Given the situation as shown in Figure 5.2, the best result might be one which produces a weighting value close to unity thus not significantly modifying the priors.

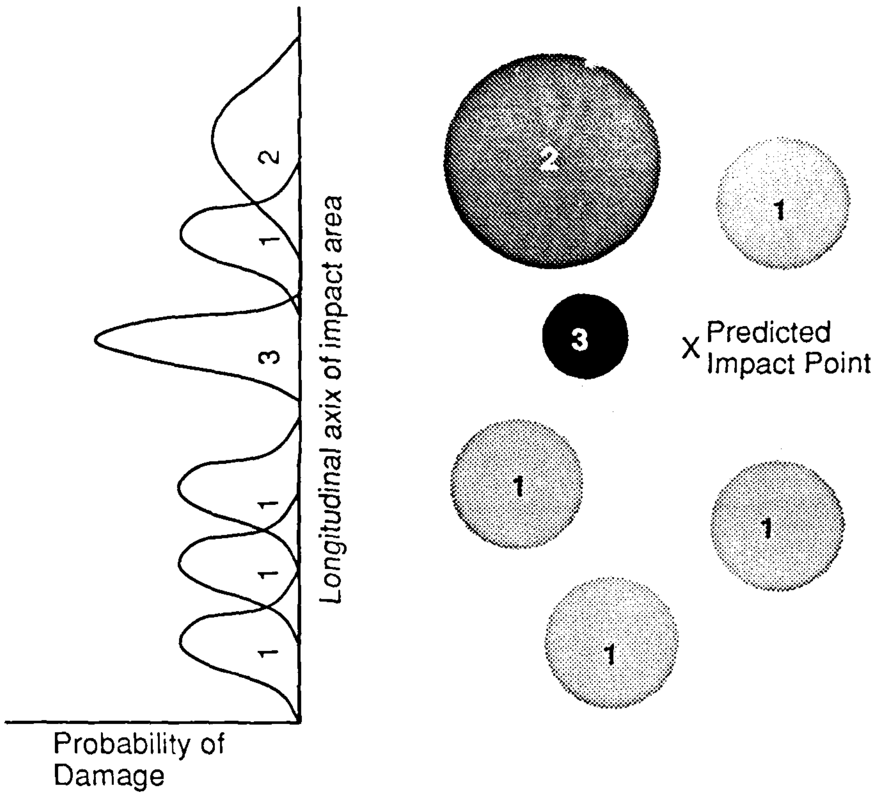

Figure 5.2 Target Expected Damage Density Functions

A different impact area with different targets and locations of targets might produce a more reliable estimate of the intended target. Consider an impact area as shown in Figure 5.3. In this example, the intended target is probably a class 2 target because most of the proportion of the expected damage is represented by class 2 targets. In this situation, the confidence in the information is significantly higher than in Figure 5.2. Therefore it is appropriate to modify the prior probabilities by a significant amount.

Even the situation shown in Figure 5.3 does not truly represent the complexity of the situation. Imagine an impact area which contains several targets all of the same type near one end of the impact area. There is a probability that the intended target lies outside of the damage area of the warhead. This situation would exist if the inaccuracy of the radar predicted an impact point so far away from the intended target that the intended target did not receive any damage from the warhead. Few if any methodologies could handle this situation.

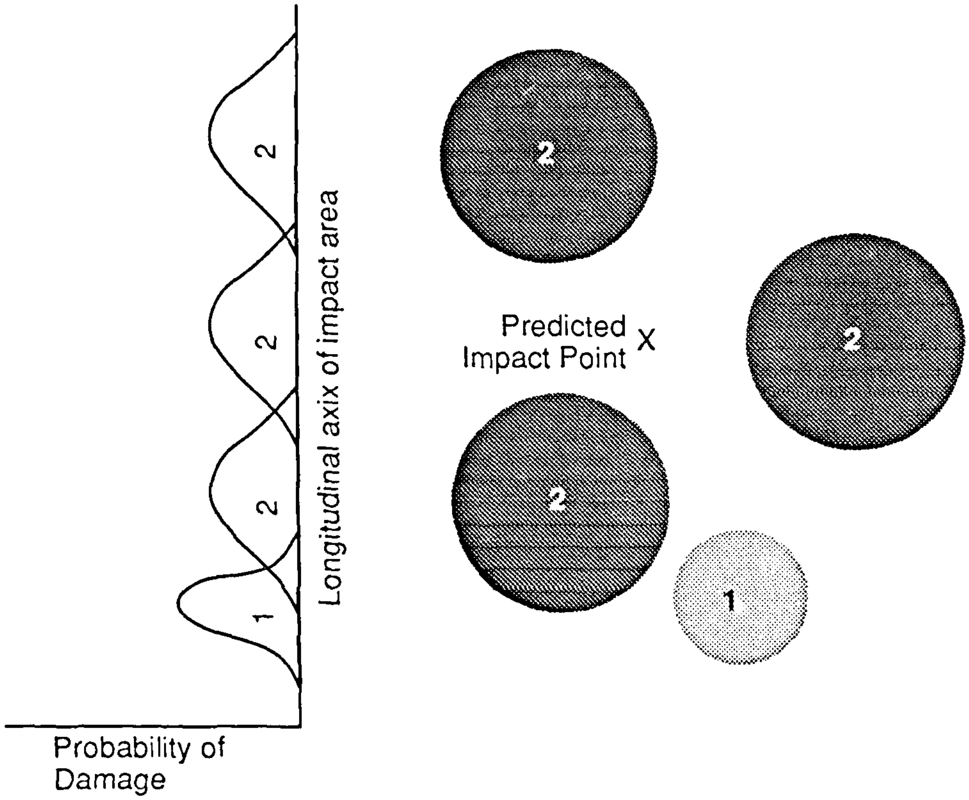

Figure 5.3 More Confident Information

Calculating the density functions of the expected damage to the targets would computationally be very difficult. The problem could be discretized by using the probabilities of damage calculated by the damage expectancy model as a substitute for the probability density of the expected damage. A table of values for each target in the area could be constructed with a weighting function being developed based on the relative amount of probability of damage occurring to each class of targets. Table 5.9 presents a simulated set of data illustrating the procedure. The data simulates the impact area and damage to targets shown Figure 5.2.

TABLE 5.9 Class Damage for Figure 5.2

Target	Probability of Damage	Target Class	Class Summary of Damage	Proportion of Damage
1	.75	1		
2	.55	1		
3	.60	1		
4	.45	1	2.35	.5875
5	.65	2	.65	.1625
6	1.00	3	1.00	.2500

The proportion of the damage to each target class illustrates that there is 3.5 times more damage to class 1 targets than class 2 targets. Unfortunately, trying to create a conditional probability out of this data proved to be beyond the scope of this research. The problem still comes down to trying to resolve the uncertainty in the data when there are a large number of possible targets in the area. The next section of this chapter discusses the second technique which might prove useful in resolving the uncertainty.

Bayes' Theorem Again. One of the possible problems with the methodology as it is applied is that too much data is being aggregated to construct the conditional probabilities. By considering the warhead as being intended for a specific target in a group of possible targets based on the largest expected damage, a large amount of data is being ignored. Instead of treating the warheads as being assigned to a specific class of targets as a 0 – 1 outcome, 1 for the class of targets with a target receiving the most damage and 0 for all other target classes, perhaps each warhead should get a discrete probability for its likelihood of being each of the four target classes. In other words, given the situation shown in Figure 5.2, a vector of discrete probabilities could be developed which for this particular example would look like (.6, .15, .25, .00). This vector of probabilities means that there is a .6 chance that the warhead is intended for a class 1 target, .15 probability that it is intended against a class 2 target, .25 chance that the intended target is from class 3, and no chance that the intended target is class 4. These vectors of probabilities could then be used with Bayes' Theorem to generate posterior probabilities for each warhead being a specific class. Figure 5.4 shows what these probabilities might look like.

These probabilities would be updated at each point in time as new information was received for each warhead. The effect of the new information would be to change the height of the probabilities distributions for each class of targets. Two problems exist with this technique. First, generating the discrete probabilities would be difficult for the same

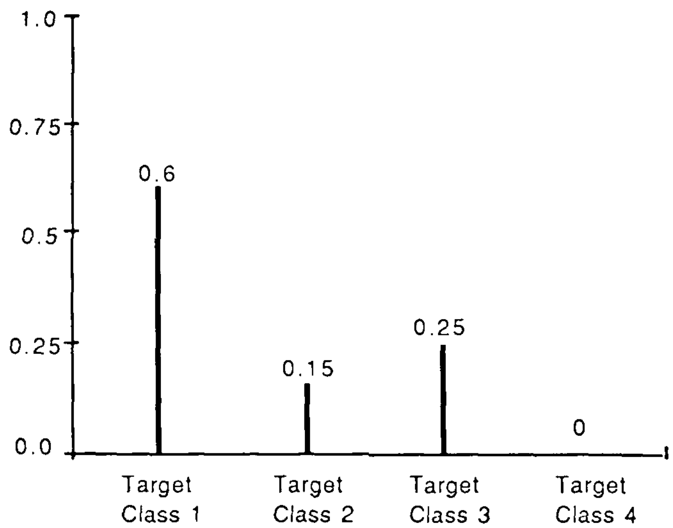

Figure 5.4 Bayesian Approach by Warhead

reasons as previously discussed. Some way would still have to be found to calculate the conditional probabilities and make them dependent on the accuracy of the radar. Second, once the discrete probabilities were generated, a technique would have to be developed to combine the probability distributions for all fifteen warheads in the attack. However, this technique, if it could be developed, might generate some good results.

Using Bayes' Theorem to update the posterior probability of each warhead being targeted against a specific target class captures the filtering property desired in the research. The purpose of using Bayes' Theorem rather than treating the problem with a traditional statistical approach is that a method was desired which would use both a decision maker's prior perception of the state of an outcome and would filter the results over time so that random fluctuations in the data would be dampened. Since Bayes' Theorem is applied to each warhead instead of the aggregated data, a closer representation of reality might be obtained. The complexities of the situation might be more easily captured one warhead at a time instead of aggregating the warheads together.

Heuristic Weights. The final technique which might be developed is to examine the targets which are being attacked by each warhead and to monitor how the numbers and types of targets change over time. A table of data could represent how the character of the attack is changing over time for each warhead. Table 5.10 represents what one of these tables might look like.

TABLE 5.10 Attack Character for Warhead #1

Time Before Impact (sec)	Target # (Damage) Target Class				
900	3 (.95) 1	15 (.05) 1	88 (.85) 2		
870	3 (.79) 1		88 (.99) 2	114 (.21) 2	
840	3 (.53) 1	15 (.08) 1	88 (.90) 2	114 (.17) 2	148 (.09) 4
810	3 (.15) 1		88 (.97) 2	114 (.09) 2	148 (.10) 4
780			88 (.99) 2	114 (.05) 2	148 (.05) 4
.					
.					
.					
600		15 (.01) 1	88 (.99) 2		

In Table 5.10, even though the initial observation would characterize the warhead as attacking target #3, a class 1 target, over time a pattern develops that target #88 which is a class 2 target is probably the intended target. If some way could be found to capture this "feeling" about the character of this particular warhead, then the entire attack might be able to be characterized in the same manner. The solution would probably involve some sort of heuristic that would generate a set of weights to be applied to Bayes' Theorem.

A closer examination of the data in Table 5.10 illustrates the difference between the currently proposed solution methodology and a methodology based on capturing the uncertainty in the observed sample. Under the currently proposed methodology, the target and target class under attack at 900 seconds before impact would be target # 3, a class 1 target because it receives more damage ($P_k = .95$) than any other target close enough to receive any damage. But as can be observed as the predicted impact point becomes more accurate, the actual intended target becomes target # 88, a class 2 target. The estimate of the intended target and target class at 900 seconds would represent a misclassification. From examining the data, it is obvious that some method is needed which can capture the uncertainty in the observed sample.

The solution to the problem of describing the uncertainty associated with the sample can be illustrated by returning to the example used earlier about the urn containing green and red balls. Under the analogy, if the color of the balls in the sample which is drawn is not completely known then current Bayesian analysis does not yield a result. This condition happens because under traditional applications, the sample is treated as having discrete states. It either is a red ball or it is a green ball, not a 30% green ball and 70% red ball. Uncertainty about the color of each ball leads us to having uncertainty about the sample. There are several samples possible and therefore there is a distribution associated with getting a particular sample.

In this research, the exact outcome of the observation of a particular warhead is really not known. Classifying it as attacking a class 1 target or a class 2 target ignores too many of the complexities of the problem. Since each warhead's intended target cannot be quantified as class 1, 2, 3, or 4, then the observed sample cannot really be measured as 7 warheads attacking class 1 targets, 4 warheads attacking class 2 targets, 1 warhead attacking class 3 targets, and 3 warheads attacking class 4 targets. The sample really has probabilities associated with the number of warheads assessed as attacking a specific target class. In other words, each of the Xs have a probability distribution associated with them. Seven warheads attacking class 1 targets cannot in reality be observed. But in principle, a probability distribution that the real sample has 0, 1, 2, 3,...15 warheads attacking class 1 targets can be constructed.

This constructed distribution is used to weight the sample information contained in Table 4.2. That tabel contains "values" of $P(\theta|x)$ which must be weighted by the probability that a particular value of **x** has been observed. Instead of using a single column of Table 4.2 to update the prior probabilities of θ, several columns will be used with each column being assigned a specific value of the weighting function.

This technique does not provide a purely straight-forward mathematical treatment of the problem but it may be the only way to capture the complexities of the problem. When the accuracy of the radar is such that many targets are in the area of possible targets, a simple application of Bayes' Theorem does not produce a correct estimate of the intent. The simple application of Bayes' Theorem ignores too many of the complexities of the problem. This research has not discovered a way to mathematically represent the essential factors of the problem. The next sections present the results obtained given the methodology proposed in chapter IV. Some of the experimentation could not be accomplished due to the inability of the methodology to generate a good estimate of intent when the radar uncertainty was large.

Results of Sub-objectives

Results obtained through experimentation as part of the research will be presented in this section for each sub-objective. There were four sub-objectives which when met will satisfy the overall research objective. Not all of the sub-objectives could be completely accomplished due to the inability of the methodology to perform under high radar uncertainty. The inability to meet the last sub-objective did not adversely affect the results of the research. The failure of the methodology to perform in a high radar uncertainty environment was made worse by the closeness of the targets which were randomly picked from the target data base. However, to present a fair evaluation of the methodology, the same attack scenario was used in most of the analysis. Some sensitivity analysis was conducted using different attack scenarios. The different attack scenarios were also randomly drawn from the target data base.

MOE Sub-objective. The first sub-objective was to develop a measure of effectiveness (MOE) which could be used to evaluate a prospective methodology for determining the intent of a limited nuclear attack. The measure of effectiveness which was developed by this research was a "correctly-classified" rate. The idea for this MOE was developed from the confusion matrix used in multivariate analysis. Typical results of one of the runs in the experimentation appear in Table 5.11.

This MOE is easy to calculate and easy to display but it does ignore one vital aspect of the problem. This MOE treats all targets of a class as though they were the same target. If the methodology determines that the intended target is Beale Air Force Base but the actual intended target is Castle Air Force Base, then the methodology counts this as a correctly classified target because they are the same class of targets. The MOE percentage will be affected only when the misclassification involves a different class.

		Predicted Target Class			
Actual Tgt Class	**Number of warheads**	**1**	**2**	**3**	**4**
1	5	6	0	0	0
2	4	0	4	0	0
3	3	0	0	1	0
4	3	0	0	0	4

TABLE 5.11 Sample Results of MOE

Percentage of targets correctly classified = .9333

In defense of this method for calculating a MOE the question can be asked, "Does it matter which class 3 target they were trying to hit as long as the methodology correctly determines that a class 3 target is under attack?" Since the data will be reported to CINC NORAD by class of targets, the misclassification within the class is really irrelevant. Another point in defense of the MOE is that it represents a much better measurement of the methodolog's attempt to classify targets than any other method which was investigated.

The only other approach would have been to keep track of the actual intended target of each warhead and compare the determined target against the intended target and calculate a correctly classified percentage from that information. This approach would have been a little more difficult and probably would not have yielded an MOE value much different than the one already being obtained through an easier approach. Therefore, the MOE as developed will be accepted here as the best measure for evaluating the ability of a methodology to determine the intent of a limited nuclear attack. The MOE is a surrogate measure for the confidence level of the results. The higher the MOE, the more confidence should be placed in the estimates of intent generated by the methodology. As seen earlier in this chapter, an MOE of 75% or below does not yield good estimates of the intent of the attack.

Sensor Accuracy Sub-objective. The second sub-objective was to find the sensor accuracy needed to enable the missile warning system to provide attack characterization at the 75, 90, and 98% correctly classifed levels. This sub-objective was met by applying search procedures to the problem. The radar parameters were improved until each correctly classifed level could be met. The search began with the current radar accuracy which is shown in Table 5.1. Ten runs were accomplished at each radar setting to obtain an average value because each run of the model is not a unique outcome. The final results are presented in Table 5.12, Table 5.14, Table 5.16, and Table 5.17.

TABLE 5.12 Experimental Runs for 75% Correctly Classified Level

Run #	MOE
1	0.7333
2	0.8000
3	0.8000
4	0.7333
5	0.8000
6	0.7333
7	0.7333
8	0.7333
9	0.7333
10	0.7333
Avg	**0.7533**

75% Correctly Classifed Level. The results shown in Table 5.12 were obtained by evaluating the current radar accuracy. These results show that by using the proposed methodology without any improvements in radar capability, the current attack warning and characterization system could classify 75% of the warheads correctly. As previously discussed, the estimates of the proportions of the attack which were intended for each specific class of targets are very inaccurate at the 75% correctly classifed level. Using the present day radar accuracy and the methodology as proposed would produce results which would not be a very reliable source on which to base a response decision. However, the results do offer an improvement over what is currently available to CINC NORAD and his advisors. Developing an improved methodology theoretically based on Bayes' Theorem as discussed in earlier sections of this chapter could significantly improve the results without an increase in radar accuracy. This possibility encourages further research in finding or developing an improved methodology.

90% Correctly Classifed Level. In order to obtain a higher correctly-classifed rate using the proposed methodology, the accuracy of the radar had to be improved. After a search of possible settings of radar accuracy parameters, the parameter values as shown in Table 5.13 were found which yield the desired correctly-classifed level.

TABLE 5.13 Radar Accuracies for 90% MOE
(one-sigma values)

PARAMETER	ACCURACY
X	10.0 meters
Y	10.0 meters
Z	10.0 meters
V_x	6.0 meters/sec
V_y	2.0 meters/sec
V_z	6.0 meters/sec

These radar accuracy levels would yield a correctly classifed rate of 90%. At this level, the confidence that a decision maker could place in the estimate of the proportion of the attack which is a specific target class would begin to be fairly reliable. It should be recognized that the radar parameter values given in Table 5.13 represent only a guideline from which to design the radar. The actual values of accuracy could be different for each parameter and the same correctly classifed rate could be attained. Some analysis has been conducted in the past to determine the correlation between the various radar parameters [28]. It might be true that the same radar accuracy can be attained by only changing the value of one or two of the parameters. The analysis of the correlation between the radar parameters was beyonc' the scope of this research. The results from the ten runs of the experiment at the accuracy values in Table 5.13 are shown in Table 5.14.

TABLE 5.14 Experimental Runs for 90% Correctly Classified Level

Run #	MOE
1	0.8667
2	0.9333
3	0.9333
4	0.8333
5	0.9333
6	0.9333
7	0.9333
8	0.8667
9	0.9333
10	0.8667
Avg	**0.9033**

The level of accuracy needed to give a correctly classifed rate of 90% is technically feasible. Discussions with Mr. Larry Lillard, a trajectory analyst at Foreign Technology Division at Wright-Patterson AFB, revealed that improved radar systems are being developed which do possess the accuracy necessary to meet the specifications of Table 5.13 [28]. The results of this anay is suggest that given improved radar accuracy and using the proposed methodology, a fairly reliable of Soviet intent could be obtained from attack warning and characterization data.

98% Correctly Classifed Level. Searching for the radar accuracy necessary to yield a 98% correctly classifed level proved to be impossible. No amount of improvement in radar accuracy was found which would yield a 98% correctly classifed rate. Table 5.15 presents the values of the radar accuracy parameters which were attempted first to meet the desired correctly classifed rate.

TABLE 5.15 1st Radar Accuracy Attempted for 98% MOE
(one-sigma values)

PARAMETER	ACCURACY
X	5.0 meters
Y	5.0 meters
Z	5.0 meters
V_x	3.0 meters/sec
V_y	1.0 meters/sec
V_z	3.0 meters/sec

TABLE 5.16 Experimental Runs for 98%
Correctly Classified Level, 1st Attempt

Run #	MOE
1	0.9333
2	0.9333
3	1.0000
4	0.8333
5	0.9333
6	0.9333
7	0.9333
8	0.9333
9	1.0000
10	0.9333
Avg	**0.9366**

Since the level of radar accuracy in Table 5.15 did not yield the desired correctly classifed rate, the radar was improved to the point of having no error in the data introduced as a result of radar measurement. This situation equates to the "perfect information" condition where the only uncertainty in the data is due to the missile CEP. The missile CEP was set at 300 meters for all of the experimentation under this sub-objective. Table 5.17 presents the results obtained under perfect information.

TABLE 5.17 Experimental Runs for 98% Correctly Classified Level, Perfect Information

Run #	MOE
1	0.9333
2	0.9333
3	1.0000
4	1.0000
5	0.9333
6	0.9333
7	0.9333
8	0.8667
9	1.0000
10	1.0000
Avg	**0.9533**

These results show that due to the complexities of the problem, that is, some targets positioned collateral with one another, the desired correctly classifed level of 98% could not be attained using the proposed methodology. These results provide the motivation for continued research in finding a improved methodology which could more accurately determine the intent of the Soviet limited nuclear attack. A high degree of confidence is needed in intent determination for obvious reasons. The cost of misinterpreting the intent of the attack could have catastrophic effects on the outcome of a nuclear conflict.

Sensitivity Analysis on Radar Accuracy. The changes in the values of the MOEs obtained at the different accuracy levels suggest that the percentage of targets correctly classifed under the methodology is sensitive to the accuracy of the radar. A sensitivity analysis was conducted by running an experiment at six different levels of accuracy. The results of this experimentation are contained in Appendix M. To illustrate the affect of radar accuracy on the MOE, Figure 5.5 shows the change in the MOE over time at the six different levels of accuracy. The levels of radar accuracy are defined in Table 5.18.

TABLE 5.18 Radar Accuracy Levels
(one-sigma values)

PARAMETER	ACCURACY					
	Level 1	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
X meters	25.0	20.0	15.0	10.0	5.0	0.0
Y meters	25.0	20.0	15.0	10.0	5.0	0.0
Z meters	25.0	20.0	15.0	10.0	5.0	0.0
V_x meters/sec	15.0	12.0	9.0	6.0	3.0	0.0
V_y meters/sec	5.0	4.0	3.0	2.0	1.0	0.0
V_z meters/sec	15.0	12.0	9.0	6.0	3.0	0.0

The results of the sensitivity analysis indicates that the percentage of targets correctly classifed, the MOE, is sensitive to the accuracy of the radar. As the radar improves, the MOE generally increases. This result substantiates the *a priori* belief concerning the sensitivity of the MOE to radar accuracy. The significance of this substantiation is that intent determination can be improved through radar accuracy improvements using the methodology as proposed.

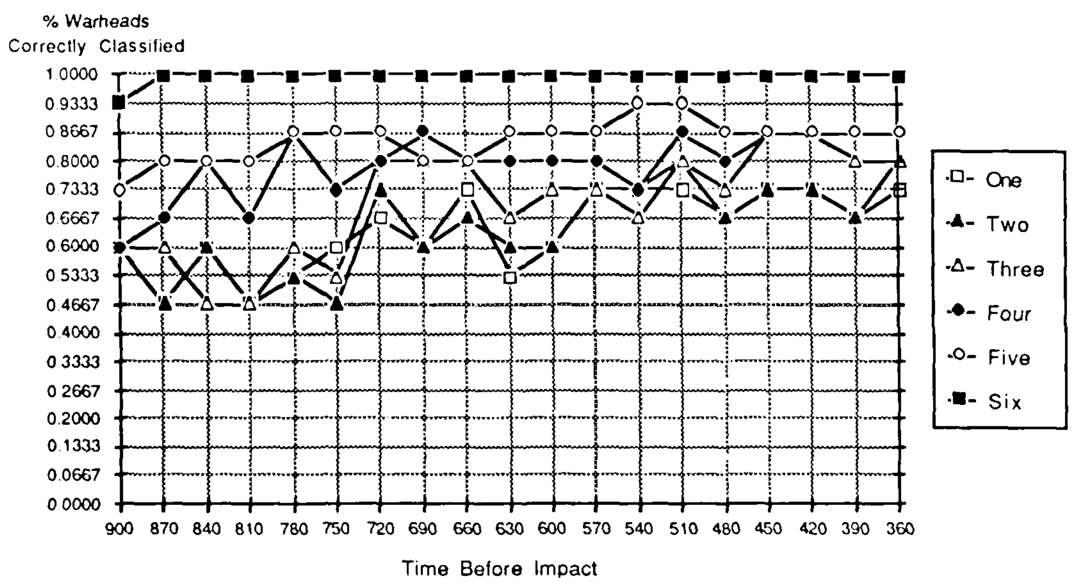

Figure 5.5 Radar Sensitivity

CEP Sensitivity Sub-objective. This sub-objective analyzed how missile accuracy affects attack characterization. This sub-objective was accomplished by conducting the experimentation at four levels of missile CEP which are defined in Table 5.19. The results of the experiment are contained in Appendix N and illustrated in Figure 5.6.

TABLE 5.19 Missile CEP Levels (meters)

	CEP			
	Level 1	**Level 2**	**Level 3**	**Level 4**
CEP (meters)	900	600	300	0

The results in Figure 5.6 illustrate that the MOE is not significantly sensitive to missile CEP up to 900 meters. Soviet CEPs have been reported many times since the mid 1970s as being better than 900 meters [14: 164]. By using 900 meters as one of the levels of the sensitivity analysis, the most severe test conditions have been applied to the experiment. Level 4 CEP is set at zero meters meaning that the reentry vehicle would exactly hit its target every time. The interesting result to note here is that even with 0 CEP, the best intent prediction that can be made is 86.7% using the proposed methodology. This result illustrates explicitly the problem described in Chapter IV with using the methodology as proposed without any weighting function applied and given the closeness of some of the targets. The CEP sensitivity analysis was performed with the radar accuracy at the values which yield a 90% correctly classified rate at 300 CEP for missile accuracy.

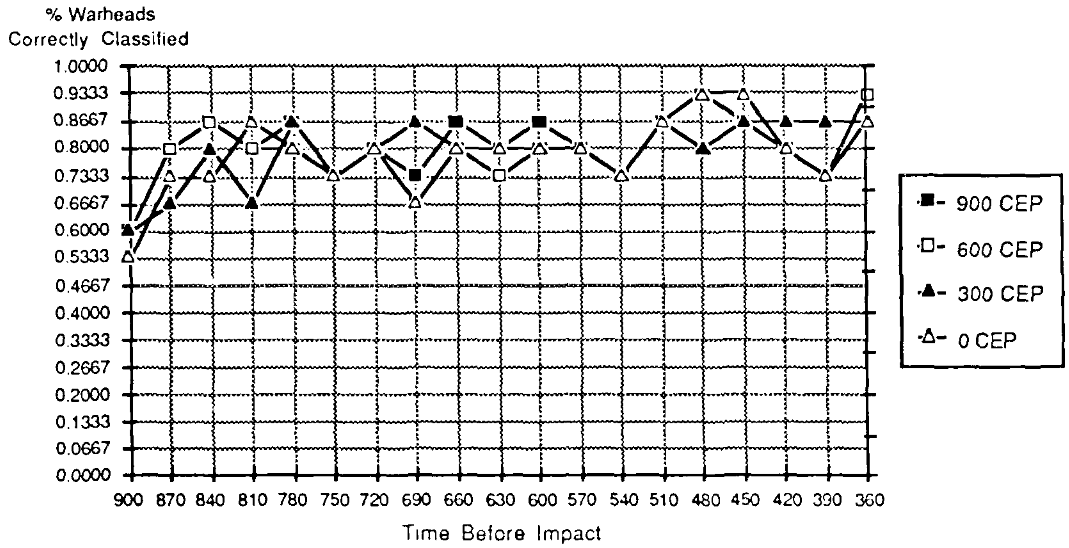

Figure 5.6 CEP Sensitivity Analysis

From Figure 5.6, it can be determined that the percentage of warheads correctly classifed is not significantly affected by CEP. Under any four of the CEP levels, the percentage of warheads correctly classifed varies mostly between 73.3% and 86.7%. No particular setting of CEP, especially the zero error level, shows any particular improvement over the other settings. The reason for this result is that most of the uncertainty in the attack warning and characterization problem is due to the radar measurement error not the missile flight dynamics error. The error at the 6 minute point prior to impact is still a few thousand meters as a result of the radar and only a few hundred meters as a result of the missile CEP.

Time Sensitivity Sub-objective. This sub-objective's purpose was to determine if the "optimal" time could be found where the cost of a misclassification was equal to the cost of waiting for better information. At the point where the two costs are equal, the total costs due to the two factors is minimized. The essential aspects of this objective can be represented as in Figure 5.7. The costs due to waiting for better information increases drastically at the 6 minute point prior to impact because beyond that time the strategic forces would not be able respond before they were in jeopardy of destruction from the enemy's weapons.

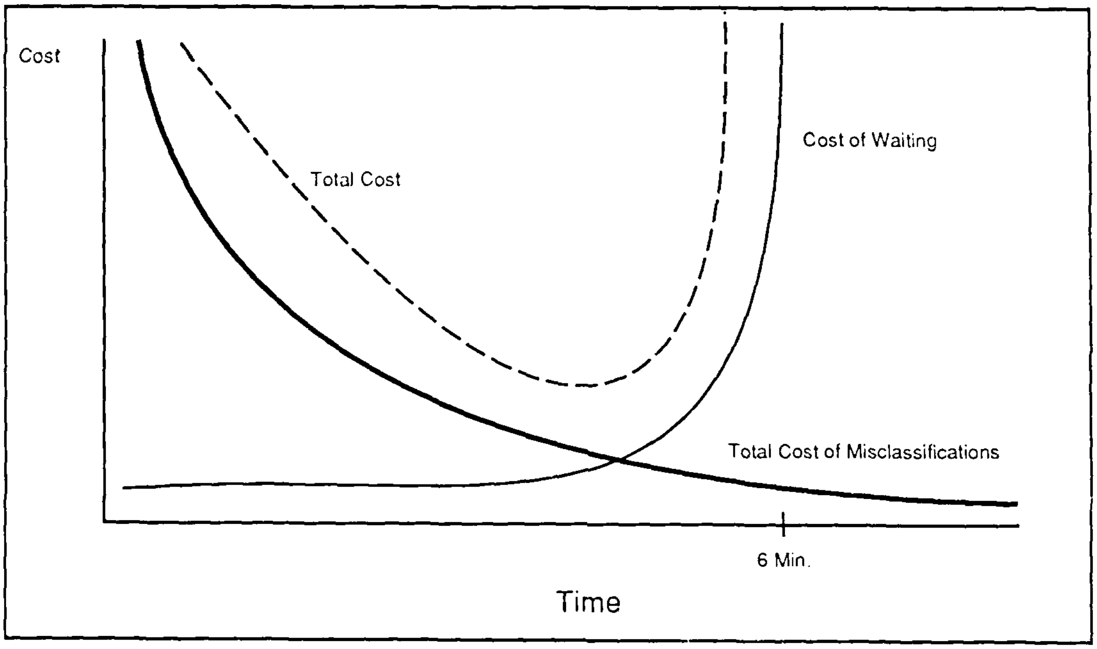

Figure 5.7 Time Sensitivity Analysis

Unfortunately this sub-objective could not be accomplished due to the inability of the methodology to correctly classify warheads at the 98% level which was the stated level of performance in the objective. Another important reason for not being able to obtain this sub-objective is that there is too much still unknown about capturing the uncertainty associated with the predicted impact points. Before reliable misclassification cost functions could be constructed as shown in Figure 5.7, a much better understanding of the uncertainties of the problem and how to quantify those uncertainties would have be be achieved.

This result means that, given the proposed methodology, no time before the 6 minute point was found where a decision could be made that met the 98% correctly-classified warheads criteria. This area again is one which is available for future research. Given a better methodology for capturing the complexities of the problem, the cost of waiting for more reliable information could be found and compared to the cost of misclassifying the warheads. The optimal time for making the decision concerning the Soviet intent could thus be found by using a better methodology which resoloves more of the uncertainty in the problem.

Attack Scenario Sensitivity. The final sensitivity analysis conducted was to vary the types of attack and determine the effect on the percentage of targets correctly classified. The sensitivity analysis was performed by choosing four different attack scenarios. In each of the four scenarios, a different target class was exclusively attacked. This meant that since there are only 15 targets in each of the third and fourth classes, every target in those classes were attacked. The percentages of warheads correctly classifed under each of the attack scenarios are presented in Table 5.20.

TABLE 5.20 Attack Scenarios

	Type of Attack			
	Class 1	**Class 2**	**Class 3**	**Class 4**
MOE(at 360 sec)	1.0000	1.0000	0.4667	0.7333

The results in Table 5.20 indicate that if the attack is either all city/industrial targets or all conventional military targets then the proposed methodology performs quite well in determining intent. However, the intent determination becomes uncertain when the attack is purely strategic targets or command and control or communications targets. The reason for this result might be that class 1 and class 2 contain targets which are soft in comparison to the other two target classes. When there are many targets in the area, the soft targets are easily killed and the methodology detects this condition rather easily. When the targets are hard, the warhead has to land much closer to the intended target to record the same level of damage. If the radar accuracy is poor, then there is a much higher probability that the predicted impact point will be near a soft target, since there are more of them, than one of the harder targets.

The worst results occurred when the attack was against class 3 targets. These targets have the most hardness thus supporting the hypothesis that the harder targets will be misclassified more often than the softer targets. When a misclassification did occur, especially for the class 3 targets, the target class most often incorrectly chosen as the intended target was a target from class 1. These results substantiate the claim that the proposed methodology performs well enough when the uncertainty is low but when the uncertainty is high either due to radar inaccuracy or closeness of targets, the methodology fails to perform at an adequate level.

Summary

This chapter has presented the results of the experimentation and the analysis of those results. Even though some of the experimentation could not be conducted due to the inadequacy of the proposed methodology, the overall research objective was obtained. A great deal of information was gained about the intent determination problem. Unfortunately, the methodology developed was not robust when there was a large amount of radar inaccuracy such as present in current systems. When the radar accuracy is improved, the methodology performs adequately. Much more research is required to find a usable methodology which can perform at desired levels given current state-of-the-art radar systems. Some of the alternative methodologies presented in tne this chapter offer a good place to start that research.

VI. Conclusions and Recommendations

Overview

This chapter contains the conclusions derived from the results of the research effort and some recommendations based on that research. Each sub-objective will be revisited to extract the important lessons learned while conducting the experimentation. Then the research will be evaluated to determine how well it met the desired outcomes identified in chapter I. The chapter will finish with recommendations for future research.

Overall, the research showed that a methodology could be developed which would aid a decision maker such as CINC NORAD and his advisors in determining the intent of a limited nuclear attack. Unfortunately, the methodology did not prove to be robust when the accuracy of the radar is poor. The methodology that was developed was to use Bayes' Theorem to update the beliefs that a certain proportion of an attack was intended for each specific target class. These beliefs or posterior probabilities were reported at thirty second increments with the most importance report being the one at 6 minutes prior to the warheads detonating. The 6 minute time limit is used because that is the minimum amount of time for the U.S. to make a response to the nuclear attack.

Conclusions

The next few sections recap the results found under each sub-objective and then analyze those results to draw conclusions. Some of the conclusions substantiate *a priori* beliefs about some of the factors which affect the determination of intent. After the sub-objective results and conclusions are presented, the research will be evaluated in terms of how well it met the desired outcomes identified in chapter I.

MOE. The measure of effectiveness developed to evaluate the methodology for determining the intent of a limited nuclear attack performed adequately under most conditions. The measure of effectiveness used was the percentage of warheads that were correctly classifed according to intended target class. When the accuracy of the radar is poor, the methodology converges to wrong answers for the estimates of the proportion of the attack which is against each target class. This result is bad because it means that under the current state-of-the-art radar technology, the methodology would not give a very reliable estimate as to the intent of the Soviet attack. The solution to the problem of providing reliable intent determination given today's radar accuracies is to develop or refine the proposed methodology such that it is robust under the poorer radar accuracies. Suggested methods for achieving this improvement will be presented in the "recommendations for future research" section of this chapter.

Another way the proposed methodology, Bayesian analysis does not perform as desired is that when the radar accuracy is poor, the measure of effectiveness inflates the percentage of warheads correctly classified because it fails to detect a misclassification when targets from the same target class are involved. This fallacy of the measure of effectiveness was ignored during the research because the stated goal of the research was to determine intent of the limited nuclear attack by estimating what proportion of an attack was targeted against each target class. Misclassifications involving targets from the same target class were irrelevant given the objective of the research. However, a more realistic and useful measure of effectiveness would have been one that accounted for the misclassifications within target classes. With these facts in mind, the measure of effectiveness, which was the percentage of warheads correctly classifed according to the target class they were aimed at, met all the research requirements.

Radar Accuracy. The ability of the methodology to estimate the proportion of the attack which is against a particular target class was sensitive to the radar accuracy and did not perform well when the radar was very inaccurate. The current state-of-the-art radar accuracy equated to the poorest level of radar accuracy evaluated. The methodology correctly predicted the intended target class only 75% of the time under current radar accuracy. This result is significant because it illustrates the fact that the current attack warning and characterization system could not give a reliable estimate of Soviet intent when the attack is limited and the targets at risk are in a target rich envirnoment. However even when the radar accuracy is poor, the methodology does provide a better estimate of Soviet intent than the current method of attack characterization. The results of the research therefore do offer an improvement over the way attack characterization and intent determination is done now.

Values of the radar parameters were found which would correctly classify the warheads in a limited nuclear attack 75, 90, 93, and 95% of the time. Unfortunately the desired goal of 98% correctly classifed rate could not be met under any conditions. This result illustrates the difficulty in deconflicting the warheads to determine which target was really the intended one when the uncertainty is high due to the closeness of the targets.

CEP Accuracy. Sensitivity analysis was conducted on the CEPs of the Soviet missiles used in the attack. The attacking missiles were an SS-18 and an SS-19. The CEP was varied from 900 down to 0 meters. The results show that changing the CEP does not significantly affect the ability of the methodology to correctly predict the intended targets. The significance of this finding means that the estimates of Soviet CEP that the U.S. is currently using (300 meters for SS-18 and SS-19) is more than adequate for determining the intended targets of the attack. The finding also indicates that the U.S. estimate of Soviet CEPs can be in error without adversely affecting the determination of intent. The reasons for this finding is that most of the uncertainty involved in the intent determination problem is due to the radar inaccuracy and the positioning of the targets.

Time Sensitivity Analysis. This part of the research could not be conducted due to no radar accuracy being available which could yield the necessary 98% correctly classified rate as stated in the sub-objective. Another important reason for being unable to accomplish this sub-objective in addition to the radar accuracy problems was that much more work is needed in the area of accurately reflecting the uncertainty in the radar estimates of the impact points. This uncertainty needs to be captured before misclassification cost functions could be constructed. An extremely high correctly classifed rate was designated because the purpose of the sub-objective was to determine if a time existed before 6 minutes prior to impact where an extremely accurate estimate of the Soviet intent could be determined. The discovery of such a time would have given the U.S. decision makers, CINC NORAD and the NCA, more time to make the appropriate response decisions.

Attack Scenario Sensitivity Analysis. The attack scenarios were varied in the research to test the effect of having an attack which was a pure strategy (all warheads intended for one specific class). The results of this analysis showed that when the targets are soft such as a city/industrial target or a conventional military target, the methodology performs extremely well in determining the intent of the attack. When the targets are hardened, the methodology performance is inadequate. When harder targets such as a strategic military target is intended, the misclassification that usually occurs is that the nearest soft target gets chosen as the intended target. This result implies that in addition to a weighting function to account for radar inaccuracy, a weighting function should be considered which accounts for the added uncertainty due to the particular mix of targets in the impact area of the warhead. If there are several soft targets surrounding a few harder targets, the methodology needs to be capable of detecting the intent if the harder targets are the intended targets.

This weighting function would have the property of being close to one when the mix of the targets was such that there are three or four different target classes represented in the impact area. This condition would create the greatest uncertainty in the data because of all the difficulties in really determining which target class was under attack. When there are only one or two different target classes represented, then the weighting function should be different than one thus allowing the prior probabilities to be changed by a significant amount. This weighting function could help improve the estimate of intent by reducing the number of misclassifications.

Desired Outcomes

The next few sections evaluate the research against the set of desired outcomes which were presented in chapter I. Some of these desired outcomes were met, others were not. It proved to be very useful to generate some desired outcomes in addition to explicit sub-objectives because some of the sub-objectives could not be met but the research could still be evaluated with respect to all of the desired outcomes. This approach allowed the benefits of the research to be measured using some heuristics in addition to using hard empirical measures.

Attack Characterization. The first desired outcome of the research was that a methodology would be found or developed which could take the received sensor data of the attack warning and assessment system and "correctly" characterize the attack. This characterization involved finding the proportion of the attack which is intended for each of the five classes of targets (city/industrial, other military, strategic military, C^3, and Washington, D.C.). The research as conducted did meet this desired outcome. The Bayesian analysis methodology along with the damage expectancy model does "correctly" characterize the attack if the radar is not too inaccurate. When there is a large amount of radar inaccuracy, the methodology fails but it still offers a improved method of determining intent over the way it is currently done which is not at all or very little using only heuristics

Determine Confidence Intervals. The second desired outcome was once the attack had been characterized, that estimates could be made of the confidence intervals associated with the proportions of each target class under attack. These confidence intervals of proportions would help CINC NORAD in formulating his assessment of the attack. The research used a unique technique for constructing the confidence intervals around the estimates of the proportions of the attack which were intended for each target class. Using the output of the posterior probability distribution, the probability density was summed over the values of θ starting around with the values of θ around the point estimate until the desired confidence level was met. A confidence level of .90 was used during the research. This technique proved very useful in adequately illustrating the true variability of the estimate of θ, the proportion of the attack against each specific target class.

Sensor Accuracy. The next desired outcome was that the level of sensor accuracy could be found which would improve the attack characterization to the point that CINC NORAD would be 98% sure what type of attack was taking place on the North American continent . It was recognized that the research might show that no amount of improvement in sensor accuracy is capable of delivering this confidence level. Other levels of confidence such as 75% and 90% were also be examined. The results of the research did find values of radar accuracy for the 75% and 90% correctly classified levels but no level of radar accuracy could deliver the 98% correctly-classifed rate. This result was caused by the inability of the proposed methodology to correctly classify the warheads when the targets in the impact area were close to one another. Note that the radar inaccuracy was not a factor in the experimentation for the 98% correctly-classified rate because it was set to the "perfect information" setting which was zero error introduced as a result of radar measurement.

Understanding Attack Assessment System. The fourth desired outcome was that a clearer understanding of the attack assessment system could be gained by investigating all of the factors which affect target characterization. This investigation was accomplished by performing sensitivity analysis on the major factors in the attack assessment system. These major factors are the accuracy of the missiles, the accuracy of the radar, the distribution of the targets, and the actual nature of the attack. The research shows that attack characterization and intent determination is sensitive to the accuracy of the radar, the distribution of the targets, and the type of attack occurring.

Dealing with Uncertainty. Finally the last desired outcome was that through the research, better understanding could be gained concerning how intent is determined when there is a large amount of uncertainty involved. This area is the largest contribution of the research. Several discoveries were made about the complexity of trying to ascertain intent when there is a large amount of uncertainty involved. The problem is made worse by the fact that the uncertainty is caused by several factors. There is uncertainty due to radar inaccuracy, missile inaccuracy, target distribution and closeness, and the hardness of the targets which is dependent on their target class. These complexities caused the simple Bayesian analysis methodology proposed as a method for determining intent to be inadequate. Treating the sample as a set of four observations from binomial distributions ignored too many of the complexities and interactions of the underlying factors in the problem. The two outcomes under the binomial treatment were that the warhead either was attacking the particular target class of interest or that it was attacking one of the other target classes. This approach also ignored the interactions in the sample among the four target classes. The numbers of warheads observed as attacking each of the four target classes are not all independent. The "recommendations for future research" section of this chapter will expound on some of the discoveries made in the area of understanding how uncertainty affects intent determination.

Recommendations for Future Research

There are several problem areas which were found during the research which were not adequately addressed. These problems constitute topics for future research. Many discoveries were made during this research but few answers were obtained. The problem of intent determination in the presence of uncertainty is a much more complicated problem than originally anticipated.

Weighting Function. The first of these areas is finding a weighting function which can be used to modify the Bayesian algorithm used to update prior probabilities. The weighting function would have the property of being close to unity when the variance in the radar information is high and different than unity when the variance is low. This property of the weighting function is desirable because the variance of the radar information changes throughout the intent determination process. The information being used to update the prior probabilities becomes more reliable over time. A decision maker needs the feature of modifying his prior probabilities when confidence in the new information is high and not modifying or modifying very little his priors when confidence in the information is low. Several different approaches were identified for creating this weighting function but no particular technique seemed to have an advantage over the others. In addition, there are probably several other techniques for creating a weighting function which were not even addressed.

Cost of Additional Information. Another area ripe for research is finding the point when the benefit of waiting for additional information which is more accurate is outweighed by the cost of waiting longer to make the intent determination decision. Given a better algorithm for determining intent, there probably exists a point before the 6 minute point prior to impact where the estimates of intent are no longer changing by a significant amount. This point in time where the added benefit is offset by the additional cost would be the optimal time for making a decision as to Soviet intent. Waiting longer would not gain any more understanding it would only give crews less time to respond to the threat.

Determination of Intent. The final area of research which could be pursued is how to take the empirical estimate of intent as identified in this research and combine that with the non-empirical information which would be available for determining intent. There are other factors such as the world situation, previous military activity, intelligence information, and national policy which would affect the overall determination of Soviet intent in a nuclear conflict. This research has attempted to find a very crucial piece of data in the overall problem of determining the intent of a limited nuclear attack. It was felt at the beginning of the research that if an empirical estimate could be made of the proportion of the attack which is against each target class, then the overall intent determination process would be much easier. This goal was not fully realized but there is hope that future research will provide that reliable empirical estimate of intent. Then a methodology such as artificial intelligence embedded in a decision support system could be developed which would combine all of these aspects of intent determination to provide a decision maker with a good estimate of Soviet intent in a limited nuclear attack.

Appendix A Actual Target Base

TGT ID	TGT CLASS	TGT LAT	TGT LON	TGT NAME
1	1	37.45	-122.1357	ALAMEDA
2	1	34.1413	-118.055	ALHAMBRA
3	1	33.2615	-117.5601	ANAHEIM
4	1	38.3145	-121.2225	ARDEN
5	1	35.2013	-119.0436	BAKERSFIELD
6	1	34.1736	-117.5535	BALDWIN PARK
7	1	33.5419	-118.0458	BELLFLOWER
8	1	37.5608	-122.1627	BERKELEY
9	1	33.5333	-117.5714	BUENA PARK
10	1	34.1217	-118.2108	BURBANK
11	1	33.4954	-118.1619	CARSON
12	1	33.5436	-118.0339	CERRITOS
13	1	32.3255	-117.015	CHULA VISTA
14	1	33.5329	-118.1447	COMPTON
15	1	38.0242	-122.0242	CONCORD
16	1	33.1119	-117.5856	COSTA MESA
17	1	37.3912	-122.312	DALY CITY
18	1	33.5804	-118.0722	DOWNEY
19	1	34.074	-118.0735	E. LOS ANGELES
20	1	32.5027	-116.5101	EL CAJON
21	1	34.1633	-118.0018	EL MONTE
22	1	38.1501	-122.0219	FAIRFIELD
23	1	33.392	-117.5527	FOUNTAIN VALLEY
24	1	37.3915	-122.0011	FREMONT
25	1	36.4715	-119.4706	FRESNO
26	1	33.5218	-117.5842	FULLERTON
27	1	33.4809	-117.5614	GARDEN GROVE
28	1	34.0834	-118.1132	GLENDALE
29	1	33.5537	-118.1932	HAWTHORNE
30	1	37.3537	-122.0604	HAYWARD
31	1	33.4059	-118.0023	HUNTINGTON BEACH
32	1	34.0015	-118.2151	INGLEWOOD
33	1	33.0935	-117.4217	IRVINE
34	1	32.3711	-116.5639	LA MESA
35	1	33.4907	-118.0432	LAKEWOOD
36	1	33.4531	-118.15	LONG BEACH
37	1	34.0149	-118.3321	LOS ANGELES
38	1	37.3841	-120.5847	MODESTO
39	1	34.0756	-118.0419	MONTEBELLO
40	1	34.1009	-118.0458	MONTEREY PARK
41	1	38.1812	-122.1738	NAPA
42	1	32.3727	-117.5734	NATIONAL CITY
43	1	33.0605	-117.5709	NEWPORT BEACH
44	1	33.5845	-118.0519	NORWALK
45	1	37.4336	-122.1324	OAKLAND
46	1	33.1306	-117.2106	OCEANSIDE
47	1	34.0324	-117.363	ONTARIO
48	1	33.2512	-117.4712	ORANGE

49	1	34.1206	-119.1224	OXNARD
50	1	37.2728	-122.1045	PALO ALTO
51	1	34.1927	-118.0603	PASADENA
52	1	34.0442	-117.4712	POMONA
53	1	34.0529	-117.2853	RANCHO CUCAMONGA (CUCAMONGA)
54	1	33.4907	-118.2729	REDONDO BEACH
55	1	37.3114	-122.1633	REDWOOD CITY
56	1	38.024	-122.2202	RICHMOND
57	1	33.5706	-117.263	RIVERSIDE
58	1	38.2441	-121.3132	SACREMENTO
59	1	36.4533	-121.4711	SALINAS
60	1	34.0736	-117.1629	SAN BERNARDINO
61	1	32.44	-117.1112	SAN DIEGO
62	1	37.3712	-122.223	SAN FRANCISCO
63	1	37.2142	-121.5536	SAN JOSE
64	1	37.4136	-122.1224	SAN LEANDRO
65	1	37.3936	-122.2543	SAN MATEO
66	1	33.1541	-117.5556	SANTA ANNA
67	1	34.2549	-119.495	SANTA BARBARA
68	1	34.0634	-118.3636	SANTA MONICA
69	1	38.3032	-122.483	SANTA ROSA
70	1	34.1929	-118.5418	SIMI VALLEY
71	1	33.5843	-118.1205	SOUTH GATE
72	1	37.5342	-121.1424	STOCKTON
73	1	34.1149	-118.5213	THOUSAND OAKS
74	1	33.4828	-118.2001	TORRANCE
75	1	34.1259	-117.371	UPLAND
76	1	38.0631	-122.1518	VALLEJO
77	1	34.1622	-119.1644	VENTURA
78	1	36.2134	-119.1931	VISALIA
79	1	37.5844	-122.0456	WALNUT CREEK
80	1	34.0601	-117.5818	WEST COVINA
81	1	33.4452	-117.572	WESTMINSTER
82	1	34.042	-117.572	WHITTIER
83	1	32.421	-114.3741	YUMA
84	2	37.4724	-122.193	ALAMEDA NAVAL AIR STATION
85	2	33.1748	-117.2148	CAMP PENDLETON MARINE CORPS BASE
86	2	35.4118	-117.4124	CHINA LAKE NAVAL WEAPONS CENTER #1
87	2	36.3125	-117.3543	CHINA LAKE NAVAL WEAPONS CENTER #2
88	2	32.3901	-117.0813	CORONADO NAVAL AMPHIBIOUS BASE
89	2	34.5922	-117.5138	EDWARDS AF AUX NORTH BASE
90	2	34.5418	-117.53	EDWARDS AFB
91	2	33.1027	-117.4256	EL TORO MARINE CORPS AIR STATION
92	2	35.3247	-116.0746	FT. IRWIN MILITARY RESERVATION
93	2	33.4231	-118.1731	FT. MACARTHUR MILITARY RESERVATION
94	2	36.4232	-121.4407	FT. ORD MILITARY RESERVATION
95	2	34.3518	-117.23	GEORGE AFB
96	2	36.0005	-121.1309	HUNTER LIGGETT MILITARY RESERVATION
97	2	36.2	-119.5706	LEMOORE NAVAL AIR STATION
98	2	33.4724	-118.03	LOS ALAMITOS NAVAL AIR STATION
99	2	38.4	-121.2354	McCLELLAN AFB
100	2	32.5212	-117.0836	MIRAMAR NAVAL AIR STATION
101	2	32.4942	-115.4012	NAVAL AIR FACILITY
102	2	37.5033	-122.1825	OAKLAND ARMY BASE
103	2	34.3811	-118.0439	PALMDALE PRODUCTION FLT/TEST INSTLN
104	2	32.34	-117.0642	REAM FIELD NAVAL AUX AIR STATION
105	2	38.2538	-121.231	SACREMENTO ARMY DEPOT

106	2	38.154	-121.553	TRAVIS AFB
107	2	33.4219	-117.4929	TUSTIN MARINE CORPS AIR STATION
108	2	34.0844	-115.5625	TWENTYNINE PALMS MARINE CORPS BASE
109	2	32.46	-117.1023	US MARINE CORPS RECRUIT DEPOT
110	2	32.42	-117.1242	US NAVAL AIR STATION NORTH ISLAND
111	2	36.3955	-121.5113	US NAVAL POST GRADUATE SCHOOL
112	2	33.4116	-118.1922	US NAVAL RESERVE (LA)
113	2	37.4914	-122.1942	US NAVAL SUPPLY DEPOT
114	2	32.4431	-117.1502	US NAVAL TRAINING CENTER
115	2	34.0621	-117.4219	US NAVAL TRAINING CENTER (LA)
116	2	33.1546	-118.0017	US NAVY HELICOPTER FIELD
117	2	32.384	-114.3523	YUMA MARINE CORP AIR STATION
118	2	33.0532	-114.2522	YUMA PROVING GROUND (ARMY)
119	3	39.0812	-121.2642	BEALE AFB (TANKER WING)
120	3	37.2248	-120.34	CASTLE AFB (BOMBER BASE)
121	3	37.5505	-122.0341	CONCORD (NUCLEAR WEAPONS STORAGE)
122	3	32.4246	-117.1117	CORONADO
123	3	33.3852	-118.1389	LONG BEACH NAVAL SHIPYARD (NUKE SHIPS)
124	3	33.5248	-117.153	MARCH AFB TANKER WING
125	3	38.3324	-121.1748	MATHER AFB (BOMBER WING)
126	3	34.0542	-117.14	NORTON AFB BALLISTIC MISSILE OFFICE
127	3	37.5122	-122.241	TREASURE ISLAND NAVAL AIR STATION
128	3	38.033	-122.2747	US NAVAL FUEL DEPOT
129	3	32.4212	-117.1304	US NAVAL RESERVATION (NUKE STORAGE)
130	3	32.4128	-117.0858	US NAVAL STATION (NUCLEAR SUBS)
131	3	33.4257	-118.0352	US NAVAL WEAPONS STATION
132	3	38.0715	-122.1238	VALLEJO BALLISTIC MISSILE SUB CONSTR.
133	3	34.4348	-120.3436	VANDENBERG AFB
134	4	39.0559	-121.2502	BEALE AFB (PAVE PAWS, GWEN NODE)
135	4	35.4851	-120.4409	CAMP ROBERTS MILITARY RES. (EW RADAR)
136	4	32.4712	-117.0256	CHOLLAS HEIGHTS (SAN DIEGO, EW RADAR)
137	4	38.2933	-121.4101	DAVIS (EARLY WARNING RADAR)
138	4	38.2901	-121.4841	DIXON (SACREMENTO, EW RADAR)
139	4	34.5648	-117.2016	HINKLEY (EARLY WARNING RADAR)
140	4	32.3359	-117.0615	IMPERIAL BEACH NAVAL RADIO STATION
141	4	33.5429	-117.1408	MARCH AFB 15TH AF, GWEN NODE
142	4	33.5804	-117.295	MIRA LOMA (EARLY WARNING RADAR)
143	4	37.2454	-122.0248	MOFFET FIELD NAS (EW RADAR)
144	4	36.4852	-119.4744	PINEDALE (GWEN RELAY NODE)
145	4	34.072	-119.0636	PORT MUGU NAVAL AIR STATION (EW RADAR)
146	4	37.5026	-121.1609	STOCKTON (EW RADAR)
147	4	37.2406	-122.0457	SUNNYVALE (EW RADAR)
148	4	32.3428	-116.5838	US SPACE SURVEILLANCE STATION

Appendix B Sample Attack Data

RV #	Launch Latitude	Launch Longitude	Target Latitude	Target Longitude	Time Diff	Target Class	Target ID Code
1	56.40000	74.00050	38.40000	-121.2354	0.0000	2	99
2	55.33330	40.31350	33.54290	-117.1408	0.0000	4	141
3	56.40000	74.00050	37.39150	-122.0011	0.0000	1	24
4	55.33330	40.31350	39.08120	-121.2642	0.0000	3	119
5	56.40000	74.00050	37.55050	-122.0341	0.0000	3	121
6	55.33330	40.31350	33.42190	-117.4929	0.0000	2	107
7	56.40000	74.00050	32.42000	-117.1242	0.0000	2	110
8	55.33330	40.31350	39.05590	-121.2502	0.0000	4	134
9	56.40000	74.00050	34.35180	-117.2300	0.0000	2	95
10	55.33330	40.31350	34.19290	-118.5418	0.0000	1	70
11	56.40000	74.00050	32.42460	-117.1117	0.0000	3	122
12	55.33330	40.31350	34.43480	-120.3436	0.0000	3	133
13	56.40000	74.00050	35.20130	-119.0436	0.0000	1	5
14	56.40000	74.00050	33.49070	-118.0432	0.0000	1	35
15	56.40000	74.00050	38.29330	-121.4101	0.0000	4	137

Appendix C Sample Output of Predicted Impact Points

LATITUDE OF LAUNCH: 56.40000000000000
LONGITUDE OF LAUNCH: 74.00050000000000
LATITUDE OF TARGET: 38.40000000000000
LONGITUDE OF TARGET: -121.2354000000000

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.56578238181829
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.1922821907520
TIME TO IMPACT IS: 904.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.44409231543660
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2472378932810
TIME TO IMPACT IS: 874.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.34100768451214
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2951994820404
TIME TO IMPACT IS: 844.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.43706405072093
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2138246075773
TIME TO IMPACT IS: 814.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.53097573751211
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.1853836996317
TIME TO IMPACT IS: 784.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.27818018889785
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2508715539503
TIME TO IMPACT IS: 754.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.39944678354740
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2713894423914
TIME TO IMPACT IS: 724.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.47319575173736
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.1903970585251
TIME TO IMPACT IS: 694.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.39523938598292
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2270205331659
TIME TO IMPACT IS: 664.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.43574240910530
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2345883828306
TIME TO IMPACT IS: 634.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.42901808781028
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2687393289709
TIME TO IMPACT IS: 604.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.44296874930859
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2037569086552
TIME TO IMPACT IS: 574.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.52841783164620
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2230863441706
TIME TO IMPACT IS: 544.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.42307923827648
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2333726091480
TIME TO IMPACT IS: 514.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.38672214101553
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2574968375015
TIME TO IMPACT IS: 484.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.39570383985043
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2110788715076
TIME TO IMPACT IS: 454.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.37343059277773
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2509671765995
TIME TO IMPACT IS: 424.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.40901929375052
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2545598561335
TIME TO IMPACT IS: 394.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.45322769352913
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2482897424221
TIME TO IMPACT IS: 364.5148988346736

ACTUAL LATITUDE OF RV AT IMPACT IS: 38.43324597494245
ACTUAL LONGITUDE OF RV AT IMPACT IS: -121.2151769850445
TIME TO IMPACT IS: 334.5148988346736

Appendix D Sample Output of Probability of Kill

RV #	TGT ID	TGT CLASS	INTENDED CLASS	DISTANCE	TIME	PROB OF KILL
3	1	1	1	19263.7934	887.4788	0.0467
3	1	1	1	16398.5759	857.4788	0.1222
3	1	1	1	16348.5390	827.4788	0.1241
3	1	1	1	15799.6717	797.4788	0.1464
3	1	1	1	14114.5945	767.4788	0.2340
3	1	1	1	10946.5413	737.4788	0.4876
3	1	1	1	15722.6325	707.4788	0.1498
3	1	1	1	15620.9035	677.4788	0.1543
3	1	1	1	15255.9915	647.4788	0.1714
3	1	1	1	19454.4858	617.4788	0.0436
3	1	1	1	18068.7670	587.4788	0.0711
3	1	1	1	14457.3409	557.4788	0.2137
3	1	1	1	12241.4111	527.4788	0.3697
3	1	1	1	16645.2745	497.4788	0.1132
3	1	1	1	14498.8247	467.4788	0.2113
3	1	1	1	15719.6447	437.4788	0.1499
3	1	1	1	11629.8759	407.4788	0.4233
3	1	1	1	12367.1661	377.4788	0.3593
3	1	1	1	10894.0687	347.4788	0.4927
5	1	1	3	17293.3539	885.3090	0.0921
5	1	1	3	12616.9549	855.3090	0.3391
5	1	1	3	16240.1103	825.3090	0.1283
5	1	1	3	14983.4843	795.3090	0.1850
5	1	1	3	15492.6664	765.3090	0.1602
5	1	1	3	8006.9659	735.3090	0.7907
5	1	1	3	15784.8019	705.3090	0.1471
5	1	1	3	17567.8210	675.3090	0.0841
5	1	1	3	8056.1419	645.3090	0.7859
5	1	1	3	10096.5965	615.3090	0.5732
5	1	1	3	14039.4454	585.3090	0.2386
5	1	1	3	14396.5568	555.3090	0.2172
5	1	1	3	11156.1690	525.3090	0.4674
5	1	1	3	12507.4488	495.3090	0.3478
5	1	1	3	5642.0616	465.3090	0.9597
5	1	1	3	9398.6175	435.3090	0.6470
5	1	1	3	10120.6853	405.3090	0.5707
5	1	1	3	16213.0408	375.3090	0.1294
5	1	1	3	16537.1713	345.3090	0.1171
6	3	1	2	23412.9675	849.8364	0.0102
6	3	1	2	18332.8529	819.8364	0.0649
6	3	1	2	18330.4371	789.8364	0.0650

6	3	1	2	18403.1303	729.8364	0.0634
6	3	1	2	20607.9924	699.8364	0.0286
6	3	1	2	12701.2956	669.8364	0.3324
6	3	1	2	10002.3230	639.8364	0.5831
6	3	1	2	16839.4706	609.8364	0.1065
6	3	1	2	23794.2414	579.8364	0.0089
6	3	1	2	8480.4537	549.8364	0.7435
6	3	1	2	11148.5358	519.8364	0.4681
6	3	1	2	18569.0703	489.8364	0.0598
6	3	1	2	22323.6645	459.8364	0.0151
6	3	1	2	19045.9376	429.8364	0.0505
6	3	1	2	10822.3614	399.8364	0.4997
6	3	1	2	9618.8454	369.8364	0.6236
6	3	1	2	20862.6974	339.8364	0.0260
1	4	1	2	14560.4093	874.5149	0.2078
1	4	1	2	6988.5217	844.5149	0.8803
1	4	1	2	13639.8422	814.5149	0.2643
1	4	1	2	24271.3461	784.5149	0.0076
1	4	1	2	4733.8721	754.5149	0.9854
1	4	1	2	10356.4023	724.5149	0.5464
1	4	1	2	17854.9644	694.5149	0.0764
1	4	1	2	8980.4700	664.5149	0.6914
1	4	1	2	13513.2941	634.5149	0.2729
1	4	1	2	13347.8418	604.5149	0.2844
1	4	1	2	14368.6188	574.5149	0.2188
1	4	1	2	23770.8459	544.5149	0.0090
1	4	1	2	12102.5179	514.5149	0.3815
1	4	1	2	8585.1408	484.5149	0.7327
1	4	1	2	9077.6525	454.5149	0.6811
1	4	1	2	7002.6151	424.5149	0.8792
1	4	1	2	10868.1802	394.5149	0.4952
1	4	1	2	15578.4920	364.5149	0.1562
1	4	1	2	13210.8994	334.5149	0.2941
15	4	1	4	17257.5074	875.8157	0.0931
15	4	1	4	23219.4999	845.8157	0.0109
15	4	1	4	16058.4178	815.8157	0.1356
15	4	1	4	17582.5448	785.8157	0.0837
15	4	1	4	13348.2059	755.8157	0.2843
15	4	1	4	23557.4831	725.8157	0.0097
15	4	1	4	19860.7155	695.8157	0.0376

Appendix E Source Code for Simulated Attack

```
      PROGRAM MAIN
      DIMENSION NSET(10000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(10000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END
C
C
C
      SUBROUTINE EVENT(I)
         GO TO (1,2),I
1        CALL LOADDATA
         RETURN
2        CALL PICKTGT
         RETURN
         END
*
*
*
         SUBROUTINE LOADDATA
         DIMENSION NSET(10000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
C
C
       OPEN(9,FILE='ATTACKDATA.DAT',STATUS='UNKNOWN')
       WRITE(9,*),ATRIB(1),ATRIB(2),ATRIB(3),ATRIB(4),ATRIB(5),ATRIB(6),
     + ATRIB(7),ATRIB(9)
      RETURN
      END
*
*
         SUBROUTINE PICKTGT
         DIMENSION NSET(10000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        INTEGER J,K,L
*
*
*
        K = INT(ATRIB(8))
       ATRIB(9) = K
```

```
      L = L + 1
      OPEN(15,FILE='REALTGT.DAT',STATUS='OLD')
      DO 10 J=1,K
       IF (J .LE. K) THEN
        READ(15,*)ATRIB(7),ATRIB(4),ATRIB(5)
       ELSE
      ENDIF
10     CONTINUE
      REWIND 15
      ATRIB(1) = L
      RETURN
      END
```

```
GEN,RBIVINS,TGT BASE,11 16 86,1,YES,NO,YES,NO,YES,72;
LIMITS,1,10,150;
SEEDS,8725423(1),56909(2),351(3),67251(4);
NETWORK;
;     ** FIRST SET OF WARHEADS GENERATED **
;
      CREATE,0,0,6,9;
      ACT;
      ASSIGN,ATRIB(2) = 56.4000;
      ASSIGN,ATRIB(3) = 74.0005;
      ACT;
      GOON,1;
      ACT 1,,0.561,URB;
      ACT 1,,0.237,OTH;
      ACT 1,,0.101,STRT;
      ACT 1,,0.101,CCC;
;
;
;  ** SECOND SET OF WARHEADS LAUNCHED **
;
      CREATE,0,0,6,6;
      ACT;
      ASSIGN,ATRIB(2) = 55.3333;
      ASSIGN,ATRIB(3) = 40.3135;
      ACT;
      GOON,1;
      ACT 1,,0.561,URB;
      ACT 1,,0.237,OTH;
      ACT 1,,0.101,STRT;
      ACT 1,,0.101,CCC;
;
;
; PICKS THE TARGET FROM ONE OF THE CITY INDUSTRIAL TARGETS
;
URB   ASSIGN,ATRIB(7) = 1;
      ACT;
      GOON,1;
      ASSIGN,ATRIB(8) = UNFRM(0,1,0,1);
      ASSIGN,ATRIB(8) = ATRIB(8)*83;
      ASSIGN, ATRIB(8) = ATRIB(8) + 1;
      ACT;
      EVENT,2;
      ACT,,,FILE;
;
;
; PICKS THE TARGET FROM ONE OF THE OTHER MILITARY TARGETS
;
OTH   ASSIGN,ATRIB(7)=2;
      ACT;
      GOON,1;
      ASSIGN,ATRIB(8) = UNFRM(0,1,0,2);
      ASSIGN,ATRIB(8) = ATRIB(8)*35;
      ASSIGN, ATRIB(8) = ATRIB(8) + 1;
      ASSIGN,ATRIB(8) = ATRIB(8) + 83;
      ACT;
      EVENT,2;
```

```
     ACT,,,FILE;
;
;
; PICKS THE TARGET FROM ONE OF THE STRATEGIC TARGETS
;
STRT  ASSIGN,ATRIB(7) = 3;
     ACT;
     GOON,1;
     ASSIGN,ATRIB(8) = UNFRM(0,1,0,3);
     ASSIGN,ATRIB(8) = ATRIB(8)*15;
     ASSIGN, ATRIB(8) = ATRIB(8) + 1;
     ASSIGN,ATRIB(8) = ATRIB(8) + 118;
     ACT;
     EVENT,2;
     ACT,,,FILE;
;
;
; PICKS THE TARGET FROM ONE OF THE CRITICAL COMMAND AND CONTROL OR
; COMMUNICATIONS TARGETS
;
CCC   ASSIGN,ATRIB(7)=4;
     ACT;
     GOON,1;
     ASSIGN,ATRIB(8) = UNFRM(0,1,0,4);
     ASSIGN,ATRIB(8) = ATRIB(8)*15;
     ASSIGN, ATRIB(8) = ATRIB(8) + 1;
     ASSIGN,ATRIB(8) = ATRIB(8) + 133;
     ACT;
     EVENT,2;
     ACT,,,FILE;
;
FILE  EVENT,1;
TERM  TERM,15;
     ENDNETWORK;
FIN;
```

Appendix F Source Code for Trajectory Simulation Program

```
*
*
*
      PROGRAM TSP
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      REAL*8 MU,LATL,LONL,LATI,LONI,LAT,LON,LATRES,LONRES
      REAL*8 LATVX,LATVY,LATVZ,LONVX,LONVY,LONVZ,LTIME
      CHARACTER*6 ID,SOL
      INTEGER NUMRV,INDCLASS
      DIMENSION A(3,3),B(3),W(3,3),ATW(3,3),ATWA(3,3),ATWB(3),
     . DEL(3)
      COMMON/INTGRV/PGXPX,PGXPY,PGXPZ,PGYPX,PGYPY,PGYPZ,PGZPX,PGZPY,
     . PGZPZ,SMA
      DATA DM/111120./,RTD/57.29578/,MU/3.98604D14/,FTM/.3048/
     .     ,PI/3.1415927/,OMEGA/.7292115147D-4/,CC/.95/,VARO/0./
     .     ,SMI/6356750./,ITER/0/
*
      DSEED0 = 89261.D0
      DSEED1 = 90121.D0
      DSEED2 = 212543.D0
      ESTSEED = 90113.D0
*
*
      OPEN(17,FILE='ATTACKDATA.DAT',STATUS='UNKNOWN')
*
      OPEN(18,FILE='IMPEST.DAT',STATUS='NEW')
      DO 4 M=1,15
      READ(17,*)NUMRV,LATL,LONL,LATI,LONI,LTIME,INDCLASS
      HAPM = -1.0
      STEP = 30.0
      CC = .99
      MAXIT = 10
      SOL = 'S'
      Q = 0.0
      SF = 1.0
      PRINT*,'LATITUDE OF LAUNCH',LATL
      PRINT*,'LONGITUDE OF LAUNCH',LONL
      PRINT*,'LATITUDE OF TARGET',LATI
      PRINT*,'LONGITUDE OF TARGET',LONI
      PRINT*
      XO = 0.0
      YO = 0.0
      ZO = 0.0
      VXO = 0.0
      VYO = 0.0
      VZO = 0.0
      TOF = 0.0
*
      TOTTIME = 0.0
      ITER = 0
```

```
      SMA = 6378135.0
      AA = SMA**2
      BB = SMI**2
      EE = 1.- BB/AA
      SS = STEP
      IF (LONI .LT. 0.0) THEN
        LONI = LONI + 360.
      ENDIF
      LATL = LATL/RTD
      LONL = LONL/RTD
      LATI = LATI/RTD
      LONI = LONI/RTD
*
*
* GENERATE INITIAL STATE VECTOR
*
*
      IF (HAPM .LT. 0.0 .AND. SOL .EQ. 'S') MAXAP = -1
      CALL ISVEC(XO,YO,ZO,VXO,VYO,VZO,REL,LATL,LONL,HAPM,LATI,LONI,TOF,
     .  EE,SOL,Q,SF)
*
*
*
* START SEARCHING ON ESTIMATED VXO,VYO,VZO
*
*
* FILL WEIGHTING MATRIX
*
*
      W(1,1) = 1./50.**2
      W(2,2) = 1./(.0001/RTD)**2
      W(3,3) = 1./(.0003/RTD)**2
      DO 1 J=1,3
      DO 1 K=1,3
       IF (J .NE. K)W(J,K)=0.
1     CONTINUE
*
*
* INTEGRATE TO APOGEE
*
*
      CALL INTAPG(0,XO,YO,ZO,VXO,VYO,VZO,STEP,APOG)
      CALL INTAPG(1,XO,YO,ZO,VXO,VYO,VZO,STEP,APOGVX)
      CALL INTAPG(2,XO,YO,ZO,VXO,VYO,VZO,STEP,APOGVY)
      CALL INTAPG(3,XO,YO,ZO,VXO,VYO,VZO,STEP,APOGVZ)
*
*
*
      APRES = HAPM - APOG
*
*
* CALCULATE PARTIALS FOR APOGEE NUMERICALLY
*
*
      PAPPVX = (APOGVX - APOG)/.1
      PAPPVY = (APOGVY - APOG)/.1
      PAPPVZ = (APOGVZ - APOG)/.1
```

```
*
*
* INTEGRATE TO IMPACT
*
*
      CALL INTIMP(0,XO,YO,ZO,VXO,VYO,VZO,STEP,LAT,LON,TOF,RNG,SOL)
      CALL INTIMP(1,XO,YO,ZO,VXO,VYO,VZO,STEP,LATVX,LONVX,TOFP,RNG,SOL)
      CALL INTIMP(2,XO,YO,ZO,VXO,VYO,VZO,STEP,LATVY,LONVY,TOFP,RNG,SOL)
      CALL INTIMP(3,XO,YO,ZO,VXO,VYO,VZO,STEP,LATVZ,LONVZ,TOFP,RNG,SOL)
      LATRES = LATI - LAT
      LONRES = LONI - LON
*
*
* CALCULATE PARTIALS FOR IMPACT NUMERICALLY
*
*
      PLAPVX = (LATVX - LAT)/.1
      PLAPVY = (LATVY - LAT)/.1
      PLAPVZ = (LATVZ - LAT)/.1
      PLOPVX = (LONVX - LON)/.1
      PLOPVY = (LONVY - LON)/.1
      PLOPVZ = (LONVZ - LON)/.1
*
*
* FILL MATRICEES FOR LEAST SQUARES CORRECTIONS
*
*
      A(1,1) = PAPPVX
      A(1,2) = PAPPVY
      A(1,3) = PAPPVZ
      A(2,1) = PLAPVX
      A(2,2) = PLAPVY
      A(2,3) = PLAPVZ
      A(3,1) = PLOPVX
      A(3,2) = PLOPVY
      A(3,3) = PLOPVZ
      B(1) = APRES
      B(2) = LATRES
      B(3) = LONRES
      DO 20 J=1,3
      DO 20 K=1,3
       ATW(J,K) = A(1,J)*W(1,K) + A(2,J)*W(2,K) + A(3,J)*W(3,K)
20     CONTINUE
      DO 25 I=1,3
       ATWB(I) = ATW(I,1)*B(1) + ATW(I,2)*B(2) + ATW(I,3)*B(3)
      DO 25 K=1,3
       ATWA(I,K) = ATW(I,1)*A(1,K) + ATW(I,2)*A(2,K) + ATW(I,3)*A(3,K)
25     CONTINUE
       VARN = 0.0
*
      CALL INVERT(ATWA,3)
      DO 30 K=1,3
        VARN = VARN + ATWA(K,K)
       DEL(K) = ATWA(K,1)*ATWB(1) + ATWA(K,2)*ATWB(2) + ATWA(K,3)*ATWB(3)
30     CONTINUE
      VXO = VXO + DEL(1)
      VYO = VYO + DEL(2)
```

```
      VZO = VZO + DEL(3)
      IF (VARO .NE. 0.) VAR = VARN/VARO
*
*
* CHECK FOR CONVERGENCE
*
*
      ITER = ITER + 1
      IF (VAR .GT. CC .AND. VAR .LT. 1.001 .AND. ITER .GT. 2)GO TO 40
      VARO = VARN
      IF (ITER .LE. MAXIT)GO TO 1
40    CONTINUE
*
*
* CONVERT TO AZ, FPA, AND VEL
*
*
      VEL = DSQRT(VXO*VXO + VYO*VYO + VZO*VZO)
      R = REL
      RDOT = (XO*VXO + YO*VYO + ZO*VZO)/R
      FPA = DASIN(RDOT/VEL)
      AZ = DATAN2(XO*VYO - YO*VXO,R*VZO - ZO*RDOT)
      IF (AZ .LT. 0.)AZ = AZ + 360./RTD
      HAPKM = HAPM/1000.
      TOTTIME = TOF + 120
50    CONTINUE
*
*
      CALL UNCERT(XO,YO,ZO,VXO,VYO,VZO,STEP,TOTTIME,SOL,NUMRV,LTIME,
     + DSEED0,DSEED1,DSEED2,FSTSEED,INDCLASS)
4     CONTINUE
      STOP
      END
*
*
*
*
*
      SUBROUTINE ISVEC(XL,YL,ZL,VXL,VYL,VZL,REL,LATL,LONL,HA,LATI,LONI,
     + TOF,EE,SOL,Q,SF)
*
* THIS SUBROUTINE IS CALLED BY TSP AND ITS PURPOSE IS TO CALCULATE
* AN INITIAL GUESS AT A STATE VECTOR AT LAUNCH FOR A TRAJECTORY GIVEN
* THE LAUNCH AND IMPACT COORDINATES IN DEGREES AND THE HEIGHT OF APOGEE
* GIVEN IN NAUTICAL MILES. THE RESULTING STATE VECTOR VALUES WILL BE IN
* X,Y,Z,VX,VY,VZ WITH UNITS OF METERS AND METERS/SEC.
*
*
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      REAL*8 LATL,LONL,LATI,LONI,MU,IVEC,LVEC,LDOTI,LCROSB
      INTEGER QCHK,DIRFLG,ETOW,TABFLG
      CHARACTER*6 SOL
      DIMENSION A(2,2),B(2)
      DATA DM/111120./,RTD/57.29578/,MU/3.98604D14/,QCHK/1/,DIRFLG/1/,
     + PI/3.1415927/,SMI/6356750./,OMEGA/.7292115147D-4/,ETOW/1/,
     + TABFLG/0/
      GCLATL = DATAN((1.-EE)*DTAN(LATL))
```

```
      GCLATI = DATAN((1.-EE)*DTAN(LATI))
      REL = SMI/DSQRT(1.-EE*DCOS(GCLATL)**2)
      REI = SMI/DSQRT(1.-EE*DCOS(GCLATI)**2)
*
*
* CALCULATE ECI COORDINATES FOR LAUNCH
*
*
      XL = (REL) * DCOS(GCLATL) * DCOS(LONL)
      YL = (REL) * DCOS(GCLATL) * DSIN(LONL)
      ZL = (REL) * DSIN(GCLATL)
*
*
* CALCULATE ECI COORDINATES FOR IMPACT
*
*
      XI = (REI) * DCOS(GCLATI) * DCOS(LONI)
      YI = (REI) * DCOS(GCLATI) * DSIN(LONI)
      ZI = (REI) * DSIN(GCLATI)
*
*
* CALCULATE DOT AND CROSS PRODUCTS FOR TWO VECTORS
*
*
      LDOTI = XL*XI + YL*YI + ZL*ZI
*
*
* CALCULATE MAGNITUDE OF LAUNCH AND IMPACT VECTORS
*
*
      LVEC = SQRT(XL**2 + YL**2 + ZL**2)
      IVEC = SQRT(XI**2 + YI**2 + ZI**2)
*
*
* CALCULATE CENTRAL ANGLE USING BOTH ARCCOS AND ARCSIN
*
*
      CANG = DACOS(LDOTI/(LVEC*IVEC))
*
*
* CALCULATE CHANGE IN LON AND DETERMINE DIRECTION OF FLIGHT
*
*
      IF (DABS(LONI-LONL) .GT. 180./RTD) DIRFLG = -1
      IF (LONI .GT. LONL .AND. DIRFLG .EQ. 1) ETOW = 1
      IF (LONI .GT. LONL .AND. DIRFLG .EQ. -1) ETOW = -1
      IF (LONI .LT. LONL .AND. DIRFLG .EQ. 1) ETOW = -1
      IF (LONI .LT. LONL .AND. DIRFLG .EQ. -1) ETOW = 1
      IF (LONL .GT. 180./RTD .AND. LONI .LT. 180./RTD .AND. DIRFLG .EQ. -1)
     C ETOW = 1
      IF (LONL .LT. 180./RTD .AND. LONI .GT. 180./RTD .AND. DIRFLG .EQ. -1)
     C ETOW = -1
*
*
* CALCULATE AZIMUTH
*
*
```

```
      AZ = DACOS((DSIN(GCLATI)-DSIN(GCLATL)*DCOS(CANG))/(DCOS(GCLATL)*
     - DSIN(CANG)))
*
*
* CORRECTIONS FOR A WESTERLY TRAJECTORY
*
*
      IF(ETOW .EQ. -1)AZ = 360./RTD-AZ
*
*
* REVERSE TRAJECTORY IF LONG TRAJECTORY WANTED
*
*
      IF (SOL .EQ. 'L') THEN
       AZ = AZ + 180./RTD
       CANG = 360./RTD-CANG
      ENDIF
      IF (AZ .LT. 0.)AZ = 360./RTD + AZ
      IF (AZ .GT. 360./RTD)AZ = AZ - 360./RTD
15    CONTINUE
*
*
* ASK USER FOR Q IF LONG TRAJ WANTED AND BAD Q GIVEN IN NAME LIST
*
*
      IF (SOL .EQ. 'L')THEN
       IF (Q .GE. 1.2 .OR. Q .LE. 1.1)THEN
        PRINT *,'   ******* WARNING ************'
        PRINT *,'YOU HAVE REQUESTED A LONG TRAJECTORY, HOWEVER THE'
        PRINT *,'    "Q" VALUE YOU HAVE INPUT IS BAD.'
        PRINT *,'   PLEASE ENTER A "Q" VALUE AT THIS TIME.'
        PRINT *,'"Q" MUST BE GE 1.1 AND LE 1.2 AND IN DECIMAL FORM.'
        PRINT *,'        IN ORDER FOR THE PROGRAM TO WORK.'
        READ(5,*)Q
        IF (Q .GE. 1.2 .OR. Q .LE. 1.1)GO TO 15
      ENDIF
*
*
* INITIAL ESTIMATES FOR LONG TRAJ
*
*
      FX = 180./RTD - DASIN(DSIN(CANG/2.)*(2.-Q)/Q)
      FPAI = .5*FX - CANG/4.
      VELI = DSQRT(Q*MU/REL)
      SMAI = REL/(2-Q)
      EI = DSQRT(1.+Q*(Q-2.)*(DCOS(FPAI))**2)
      HA = SMAI*(1.+EI)-REL
      GO TO 30
      ENDIF
*
*
* SOLVE FOR FLIGHT PATH ANGLE AND VELOCITY IMPLICITY
* INITIAL ESTIMATE FOR FPA AND VEL FROM MAX RANGE EQUATIONS(SHORT TRAJ)
*
*
      FPAI = .25*(PI-CANG)
      VELI = DSQRT((MU/REL)*(2*DSIN(CANG/2)/(1+DSIN(CANG/2))))
```

```
*
*
* CALCULATE CENTRAL ANGLE AND HEIGHT OF APOG. FROM ESTIMATES
*
*
20    CONTINUE
      Q = VELI**2*REL/MU
      CANGI = 2.*DACOS((1.-Q*(DCOS(FPAI))**2)/DSQRT(1.+Q*(Q-2.)
     +  *(DCOS(FPAI))**2))
      SMAI = REL/(2.-Q)
      EI = DSQRT(1.+Q*(Q-2.)*(DCOS(FPAI))**2)
      HAI = SMAI*(1.+EI)-REL
*
*
* DETERMINE IF VALUES FOR CANG AND HA ARE APPROACHING TRUE VALUES
*
      IF (HA .LT. 0. .AND. SOL .EQ. 'S') HA = HAI
      DCANG = CANG - CANGI
      DHA = HA - HAI
      IF (DABS(DHA) .LT. 1.0D-8 .AND. DABS(DCANG) .LT. 1.0D-10)
     + GO TO 30
*
*
* CALCULATE PARTIALS
*
*
      PCAPVE = (8*MU*(DSIN(CANGI/2))**2)/(VELI**3*REL*DSIN(2*FPAI))
      PCAPFP = (2*DSIN(CANGI + 2*FPAI))/DSIN(2*FPAI) - 2.
      PQPVE = 2*VELI*REL/MU
      PEIPQ = ((DCOS(FPAI))**2*(Q-1))/DSQRT(1+Q*(Q-2)*(DCOS(FPAI))**2)
      PEIPFP = (-Q*(Q-2)*DCOS(FPAI)*DSIN(FPAI))/DSQRT(1+Q*(Q-2)
     + *(DCOS(FPAI))**2)
      PSMPQ = RE/(2-Q)**2
      PHAPSM = 1 + EI
      PHAPEI = SMAI
      PSMPVE = PSMPQ*PQPVE
      PEIPVE = PEIPQ*PQPVE
      PHAPVE = PHAPSM*PSMPVE + PHAPEI*PEIPVE
      PHAPFP = PHAPEI*PEIPFP
      PEIPQ = ((DCOS(FPAI))**2*(Q-1))/DSQRT(1+Q*(Q-2)*(DCOS(FPAI))**2)
*
*
* LOAD ARRAYS TO SOLVE FOR DELTA VEL AND FPA
*
*
      A(1,1) = PCAPVE
      A(1,2) = PCAPFP
      A(2,1) = PHAPVE
      A(2,2) = PHAPFP
*
      CALL INVERT(A,2)
      B(1) = DCANG
      B(2) = DHA
      DVEL = A(1,1)*B(1) + A(1,2)*B(2)
      DFPA = A(2,1)*B(1) + A(2,2)*B(2)
      VELI = VELI + SF*DVEL
      FPAI = FPAI + SF*DFPA
```

```
      TABFLG = 1
      DHAP = DHA
      GO TO 20
30    CONTINUE
      VEL = VELI
      FPA = FPAI
*
*
* CALCULATE STATE VECTORS IN ECI COORDINATES
*
*
      VS  = -VEL*DCOS(FPA)*DCOS(AZ)
      VE  = VEL*DCOS(FPA)*DSIN(AZ)
      VUP = VEL*DSIN(FPA)
      A11 = DSIN(GCLATL)*DCOS(LONL)
      A12 = -DSIN(LONL)
      A13 = DCOS(GCLATL)*DCOS(LONL)
      A21 = DSIN(GCLATL)*DSIN(LONL)
      A22 = DCOS(LONL)
      A23 = DCOS(GCLATL)*DSIN(LONL)
      A31 = -COS(GCLATL)
      A32 = 0.
      A33 = DSIN(GCLATL)
      VXL = (A11*VS + A12*VE + A13*VUP)
      VYL = (A21*VS + A22*VE + A23*VUP)
      VZL = (A31*VS + A32*VE + A33*VUP)
      RETURN
      END
*
*
*
*
      SUBROUTINE INTAPG(I,XO,YO,ZO,VXO,VYO,VZO,STEP,APG)
*
*
* THIS SUBROUTINE INTEGRATES TRAJECTORY FROM LAUNCH TO APOGEE.
* DEPENDING ON THE VALUE OF I, THE INITIAL VELOCITY IS PERTURBED IN
* ORDER TO CALCULATE PARTIALS IN THE MAIN PROGRAM.
*
*
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      CHARACTER*3 PAR
      DIMENSION STM(6,6)
      DATA SMI/6356750./,SMA/6378135./,OMEGA/.7292115147D-4/
      AA = SMA**2
      BB = SMI**2
      EE = 1. - BB/AA
      X = XO
      Y = YO
      Z = ZO
      VX = VXO
      VY = VYO
      VZ = VZO
*
      IF (I .EQ. 1) VX = VX + .1
      IF (I .EQ. 2) VY = VY + .1
      IF (I .EQ. 3) VZ = VZ + .1
```

```
      DO 5 J=1,6
      DO 5 K=1,6
        IF (J .EQ. K) THEN
          STM(J,K) = 1.
        ELSE
          STM(J,K) = 0.
        ENDIF
5     CONTINUE
      SS = STEP
      T = 0.
10     CALL INTEG(SS,X,Y,Z,VX,VY,VZ,AX,AY,AZ,STM)
      T = T + SS
      RAD = DSQRT(X*X + Y*Y + Z*Z)
      RD = (X*VX + Y*VY + Z*VZ)/RAD
      RDD = (VX**2 + X*AX + VY**2 + Y*AY + VZ**2 + Z*AZ - RD**2)/RAD
      SSTORD = -.9*RD/RDD
      SS = MIN(STEP,DABS(SSTORD))
*
      IF (DABS(RD) .LT. .0000001)THEN
        GCLAT = DASIN(Z/DSQRT(X*X + Y*Y + Z*Z))
        RE = SMI/DSQRT(1.- EE*DCOS(GCLAT)**2)
        APG = RAD - RE
      ELSE
        GO TO 10
      ENDIF
      RETURN
      END
*
*
*
*
      SUBROUTINE INTIMP(I,XO,YO,ZO,VXO,VYO,VZO,STEP,LAT,LON,T,RNG,SOL)
*
*
* THIS SUBROUTINE INTEGRATES THE TRAJECTORY FROM LAUNCH TO IMPACT.
* DEPENDING ON SELECTION OF 'I', THE INITIAL VELOCITY IS PERTURBED IN
* ORDER TO CALCULATE PARTIALS IN MAIN PROGRAM.
*
*
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      REAL*8 LAT,LON
      CHARACTER*1 SOL
      DIMENSION STM(6,6)
      DATA SMI/6356750./,SMA/6378135./,RTD/57.29578/
      DATA OMEGA/.7292115147D-4/
*
      AA = SMA**2
      BB = SMI**2
      EE = 1. - BB/AA
      X  = XO
      Y  = YO
      Z  = ZO
      VX = VXO
      VY = VYO
      VZ = VZO
*
      IF (I .EQ. 1) VX = VX + .1
```

```
      IF (I .EQ. 2) VY = VY + .1
      IF (I .EQ. 3) VZ = VZ + .1
      DO 5 J=1,6
      DO 5 K=1,6
        IF (J .EQ. K) THEN
          STM(J,K) = 1.
        ELSE
          STM(J,K) = 0.
        ENDIF
5     CONTINUE
      SS = STEP
      T = 0.
10     CALL INTEG(SS,X,Y,Z,VX,VY,VZ,AX,AY,AZ,STM)
      T = T + SS
      RAD = DSQRT(X*X + Y*Y + Z*Z)
      RD = (X*VX + Y*VY + Z*VZ)/RAD
      GCLAT = DASIN(Z/DSQRT(X*X + Y*Y + Z*Z))
      RE = SMI/DSQRT(1.-EE*DCOS(GCLAT)**2)
      SSH = -.9*(RAD-RE)/RD
      SS = MIN(STEP,DABS(SSH))
*
      IF ((RAD-RE) .LT. .0000001)THEN
        LON = DATAN2(Y,X) - OMEGA*T
        IF (LON .LT. 0.)LON = (360./RTD) + LON
         LAT = DATAN(DTAN(GCLAT)/(1.-EE))
        ELSE
          GO TO 10
        ENDIF
        IF (I .EQ. 0) THEN
          CDOT = XO*X + YO*Y + ZO*Z
          VLAUN = DSQRT(XO**2 + YO**2 + ZO**2)
          VIMP = DSQRT(X**2 + Y**2 + Z**2)
         CNTANG = DACOS(CDOT/(VLAUN*VIMP))
          IF (SOL .EQ. 'L')CNTANG = 360./RTD - CNTANG
          RNG = CNTANG*RTD*60.*1.852
        ENDIF
        RETURN
        END
*
*
*
*
      SUBROUTINE INTEG(SS,X,Y,Z,VX,VY,VZ,AX,AY,AZ,STM)
      IMPLICIT DOUBLE PRECISION (A-H,O-Z)
*
* THIS SUBROUTINE WRITTEN FOR PROGRAM TEAP, USES A FOURTH ORDER
* RUNGE KUTTA-NYESTROM INTEGRATION ROUTINE TO INTEGRATE THE FREE
* FLIGHT EQUATIONS OF MOTION. THE STATE TRANSITION MATRIX IS ALSO
* UPDATED IN THIS SUBROUTINE.
*
       COMMON/INTGRV/PGXPX,PGXPY,PGXPZ,PGYPX,PGYPY,PGYPZ,PGZPX,PGZPY,
     +  PGZPZ,SMA
      DIMENSION STM(6,6),PXPX(6,6),WORK(6,6)
      DATA ((PXPX(I,J),I=1,6),J=1,6)/36*0./,(PXPX(I,I),I = 4,6)/3*1./
*
      XN = X
      YN = Y
```

```
      ZN = Z
*
      CALL GRAVTY(XN,YN,ZN,AX,AY,AZ,1.)
*
      ANX  = 0.5*SS*AX
      ANY  = 0.5*SS*AY
      ANZ  = 0.5*SS*AZ
      BETANX = 0.5*SS*(VX + 0.5*ANX)
      BETANY = 0.5*SS*(VY + 0.5*ANY)
      BETANZ = 0.5*SS*(VZ + 0.5*ANZ)
      XN = X + BETANX
      YN = Y + BETANY
      ZN = Z + BETANZ
*
      CALL GRAVTY(XN,YN,ZN,AX,AY,AZ,-1.)
*
      BNX = 0.5*SS*AX
      BNY = 0.5*SS*AY
      BNZ = 0.5*SS*AZ
      CNX = BNX
      CNY = BNY
      CNZ = BNZ
      DELNX = SS*(VX + CNX)
      DELNY = SS*(VY + CNY)
      DELNZ = SS*(VZ + CNZ)
      XN = X + DELNX
      YN = Y + DELNY
      ZN = Z + DELNZ
*
      CALL GRAVTY(XN,YN,ZN,AX,AY,AZ,-1.)
*
      DNX = 0.5*SS*AX
      DNY = 0.5*SS*AY
      DNZ = 0.5*SS*AZ
*
*
* UPDATE THE STATE TRANSITION MATRIX, STM.  THE REQUIRED PARTIALS
* ARE CALCULATED IN SUBROUTINE GRAVTY.
*     NOTE:  PXPX IS PARTIAL XI+1 PARTIAL XI  MATRIX
*
*
       PXPX(1,1) = 1. + PGXPX*0.5*SS**2
       PXPX(1,2) = PGXPY*0.5*SS**2
       PXPX(1,3) = PXPX(1,2)*Z/Y
       PXPX(1,4) = SS
       PXPX(2,1) = PXPX(1,2)
       PXPX(2,2) = 1. + PGYPY*0.5*SS**2
       PXPX(2,3) = PXPX(1,2)*Z/X
       PXPX(2,5) = SS
       PXPX(3,1) = PXPX(1,3)
       PXPX(3,2) = PXPX(2,3)
       PXPX(3,3) = 1. + PGZPZ*0.5*SS**2
       PXPX(3,6) = SS
       PXPX(4,1) = PGXPX*SS
       PXPX(4,2) = PGXPY*SS
       PXPX(4,3) = PGXPZ*SS
       PXPX(5,1) = PXPX(4,2)
```

```
      PXPX(5,2) = PGYPY*SS
      PXPX(5,3) = PGYPZ*SS
      PXPX(6,1) = PXPX(4,3)
      PXPX(6,2) = PXPX(5,3)
      PXPX(6,3) = PGZPZ*SS
*
      DO 10 I = 1,6
      DO 10 J = 1,6
      DO 10 K = 1,6
10     WORK(I,J) = WORK(I,J) + PXPX(I,K)*STM(K,J)
      DO 11 I = 1,6
      DO 11 J = 1,6
      STM(I,J) = WORK(I,J)
11     WORK(I,J) = 0.
*
*
* UPDATE STATE VECTOR
*
*
      X = X + SS*(VX + (ANX + BNX + CNX)/3.)
      Y = Y + SS*(VY + (ANY + BNY + CNY)/3.)
      Z = Z + SS*(VZ + (ANZ + BNZ + CNZ)/3.)
*
      VX = VX + (ANX + 2.*BNX + 2.*CNX + DNX)/3.
      VY = VY + (ANY + 2.*BNY + 2.*CNY + DNY)/3
      VZ = VZ + (ANZ + 2.*BNZ + 2.*CNZ + DNZ)/3.
*
      RETURN
      END
*
*
*
*
      SUBROUTINE GRAVTY(X,Y,Z,GX,GY,GZ,PARFLG)
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
*
* THIS GRAVITY SUBROUTINE IS DESIGNED FOR THE FREE FLIGHT TRAJECTORY
* ESTIMATION AND ANALYSIS PROGRAM (TEAP). IT CALCULATES THROUGH
* THE FOURTH ZONAL HARMONIC USING A WGS-72 EARTH GRAVITY MODEL.
*
      REAL*8 J2,J3,J4
      COMMON/INTGRV/PGXPX,PGXPY,PGXPZ,PGYPX,PGYPY,PGYPZ,PGZPX,PGZPY,
     . PGZPZ,SMA
*
      DATA GM/398600.5E09/,J2/1082.62E-6/,J3/-2.52E-6/,J4/-1.66E-6
*
      R = SQRT(X**2 + Y**2 + Z**2)
      GMOR2 = GM/R**2
      AOR = SMA/R
      A2OR2 = AOR**2
      ZOR = Z/R
      Z2OR2 = ZOR**2
      XOR = X/R
      YOR = Y/R
*
      UX = -GMOR2*XOR
      UY = -GMOR2*YOR
```

```
      UZ = -GMOR2*ZOR
      V2 = 1.5*J2*A2OR2*(1.-5.*Z2OR2)
      V3 = 2.5*J3*A2OR2*AOR*(3.*ZOR - 7.*Z2OR2*ZOR)
      V4 = 15./8.*J4*A2OR2**2*(-1. + 14.*Z2OR2 - 21.*Z2OR2**2)
      GX = UX*(1. + V2 + V3 + V4)
      GY = UY*(1. + V2 + V3 + V4)
      GZ = 0.0
      IF (ABS(Z) .LE. 1.) GO TO 1
      W2 = 1.5*J2*A2OR2*(3. - 5.*Z2OR2)
      W3 = 0.5*J3*A2OR2*AOR*(-3./ZOR + 30.*ZOR - 35.*Z2OR2*ZOR)
      W4 = 5./8.*J4*A2OR2**2*(-15. + 70.*Z2OR2 - 63.*Z2OR2**2)
      GZ = UZ*(1. + W2 + W3 + W4)
1      IF (PARFLG .LT. 0.) RETURN
*
* PARTIALS. GRAVTY IS CALLED BY INTEG 3 TIMES AT EACH STEP. THE
* PARTIALS ARE CALCULATED THE FIRST TIME CALLED SO AS TO USE THE
* I'TH VALUES IN CALCULATING (PARTIAL XI+1/PARTIAL XI) THE
* ELEMENTS OF THE SYSTEM MATRIX.
*
      PGXPX = GMOR2/R*(3.*XOR**2 - 1.)
      PGXPY = 3.*GMOR2*XOR*YOR/R
      IF (ABS(Y) .GT. 1.) PGXPZ = PGXPY*Z/Y
      PGYPX = PGXPY
      PGYPY = GMOR2/R*(3.*YOR**2 - 1.)
      IF (ABS(X) .GT. 1.) PGYPZ = PGXPZ*Y/X
      PGZPX = PGXPZ
      PGZPY = PGYPZ
      PGZPZ = GMOR2/R*(3.*ZOR**2 - 1.)
*
*
* THIS COMMENT LINE CAN BE REMORED AND THE PARTIALS WRITTEN TO A FILE
*
*      WRITE(22,101)PGXPX,PGXPY,PGXPZ,PGYPX,PGYPY,PGYPZ,PGZPX,PGZPY,PGZPZ
      G = SQRT(GX**2 + GY**2 + GZ**2)
*     WRITE(6,101)GX,GY,GZ,G
101    FORMAT(9E13.6)
      RETURN
      END
*
*
*
*
      SUBROUTINE INVERT(C,N)
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      DIMENSION J(120),C(N,N)
*
* CALCULATE MATRIX NORM, PD
*
      PD = 1.D0
      DO 124 L=1,N
      DD = 0.D0
      DO 123 K=1,N
123    DD = DD + C(L,K)*C(L,K)
*
* CHECK TO SEE IF ROW L (AND COL L) IS ALL ZEROES
*
      IF (DABS(DD) .LT. .000000001)THEN
```

```
        C(L,L) = 99.*99.
      ELSE
        DD = DSQRT(DD)
        PD = PD*DD
      ENDIF
124   CONTINUE
*
      DETM = 1.
      DO 125 L = 1,N
125   J(L+20) =L
*
      DO 144 L=1,N
      CC = 0.D0
      M=L
*
* LOCATE LARGEST ABSOLUTE VALUE IN ROW L
*
      DO 135 K=L,N
      IF ((ABS(CC) - ABS(C(L,K))) .GE. 0.) GO TO 135
126   M=K
      CC = C(L,K)
135   CONTINUE
*
* CC NOW CONTAINS LARGEST VALUE IN ROW L & M IS THE COLUMN
* CONTAINING THAT VALUE.
*
* CHECK TO SEE IF LARGEST VALUE IS ON DIAGONAL.
*
127   IF (L .EQ. M) GO TO 138
128   K=J(M+20)
      J(M+20)=J(L+20)
      J(L+20)=K
*
* INTERCHANGE COLUMN L WITH COLUMN M
*
      DO 137 K=1,N
      S=C(K,L)
      C(K,L) = C(K,M)
137   C(K,M) = S
138   C(L,L) = 1.
      DETM = DETM*CC
*
* NEXT DIVIDE COLUNN BY DIAGONAL TERM
*
      DO 139 M=1,N
139   C(L,M) = C(L,M)/CC
*
      DO 142 M=1,N
      IF (L .EQ. M) GO TO 142
129   CC = C(M,L)
      IF (CC .EQ. 0.) GO TO 142
130   C(M,L) = 0.
      DO 141 K=1,N
141   C(M,K) = C(M,K) - CC*C(L,K)
142   CONTINUE
144   CONTINUE
*
```

```
      DO 143 L=1,N
      IF (J(L+20) .EQ. L) GO TO 143
131     M=L
132     M=M+1
      IF (J(M+20)  .EQ. L) GO TO 133
136     IF (N .GT. M) GO TO 132
133     J(M+20) = J(L+20)
      DO 163 K=1,N
      CC = C(L,K)
      C(L,K) = C(M,K)
163     C(M,K) = CC
      J(L+20) = L
143     CONTINUE
      RETURN
      END
*
*
*
*
      SUBROUTINE UNCERT(XO,YO,ZO,VXO,VYO,VZO,STEP,TOTTIME,SOL,NUMRV,
     + LTIME,DSEED0,DSEED1,DSEED2,FSTSEED,INDCLASS)
*
*
* THIS SUBROUTINE INTEGRATES THE TRAJECTORY FROM LAUNCH TO ACTUAL
* IMPACT WITH NOISE(UNCERTAINTY) ADDED TO THE STATE VECTOR.
*
*
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
      REAL MISLAT,MISLON,NDEV(6)
      REAL XNOISE,YNOISE,ZNOISE,VXNOISE,VYNOISE,VZNOISE,LTIME
      CHARACTER*1 SOL
      INTEGER NUMRV
      DIMENSION STM(6,6),TSTM(6,6)
      DATA SMI/6356750./,SMA/6378135./,RTD/57.29578/
      DATA OMEGA/.7292115147D-4/
*
      TOTTIME = TOTTIME - 120
      CALL GGNML(FSTSEED,1,ACQERR)
      FINDTIM = 900. + 15.*ACQERR
*
      X = XO
      Y = YO
      Z = ZO
      VX = VXO
      VY = VYO
      VZ = VZO
      AA = SMA**2
      BB = SMI**2
      EE = 1. - BB/AA
*
      DO 5 J=1,6
      DO 5 K=1,6
        IF (J .EQ. K) THEN
          STM(J,K) = 1.
        ELSE
          STM(J,K) = 0.
        ENDIF
```

```
5     CONTINUE
      CALL GGNML(DSEED0,6,NDEV)
      XNOISE = 100*NDEV(1)
      YNOISE = 100*NDEV(2)
      ZNOISE = 100*NDEV(3)
      VXNOISE = 0.1*NDEV(4)
      VYNOISE = 0.1*NDEV(5)
      VZNOISE = 0.1*NDEV
      X = X + XNOISE
      Y = Y + YNOISE
      Z = Z + ZNOISE
      VX = VX + VXNOISE
      VY = VY + VYNOISE
      VZ = VZ + VZNOISE
      SS = STEP
      T = 0.
10    CALL INTEG(SS,X,Y,Z,VX,VY,VZ,AX,AY,AZ,STM)
      T = T + SS
      CALL GGNML(DSEED1,6,NDEV)
      XNOISE = .5*NDEV(1)
      YNOISE = .5*NDEV(2)
      ZNOISE = .5*NDEV(3)
      VXNOISE = 0.005*NDEV(4)
      VYNOISE = 0.005*NDEV(5)
      VZNOISE = 0.005*NDEV(6)
      X = X + XNOISE
      Y = Y + YNOISE
      Z = Z + ZNOISE
      VX = VX + VXNOISE
      VY = VY + VYNOISE
      VZ = VZ + VZNOISE
      RAD = DSQRT(X*X + Y*Y + Z*Z)
      RD = (X*VX + Y*VY + Z*VZ)/RAD
      GCLAT = DASIN(Z/DSQRT(X*X + Y*Y + Z*Z))
      RE = SMI/DSQRT(1.-EE*DCOS(GCLAT)**2)
      SSH = -.9*(RAD-RE)/RD
      SS = MIN(STEP,DABS(SSH))
*
      IF (T .GE. (TOTTIME - FINDTIM)) THEN
      CALL GGNML(DSEED2,6,NDEV)
*
* RADAR UNCERTAINTY IS ADDED AT THIS POINT.  THESE ARE THE PARAMETERS
* WHICH ARE CHANGED TO AFFECT THE RADAR ACCURACY.
*
      XNOISE = 10.0*NDEV(1)
      YNOISE = 10.0*NDEV(2)
      ZNOISE = 10.0*NDEV(3)
      VXNOISE = 6.0*NDEV(4)
      VYNOISE = 2.0*NDEV(5)
      VZNOISE = 6.0*NDEV(6)
      XO = X + XNOISE
      YO = Y + YNOISE
      ZO = Z + ZNOISE
      VXO = VX + VXNOISE
      VYO = VY + VYNOISE
      VZO = VZ + VZNOISE
      AXO = AX
```

```
      AYO = AY
      AZO = AZ
      TO = T
      DO 6 J= 1,6
      DO 6 K=1,6
        IF (J .EQ. K) THEN
          TSTM(J,K) = STM(J,K)
        ELSE
          TSTM(J,K) = 0.
        ENDIF
6     CONTINUE
*
20    CALL INTEG(SS,XO,YO,ZO,VXO,VYO,VZO,AXO,AYO,AZO,TSTM)
      TO = TO + SS
      CALL GGNML(DSEED1,6,NDEV)
      XNOISE = .5*NDEV(1)
      YNOISE = .5*NDEV(2)
      ZNOISE = .5*NDEV(3)
      VXNOISE = 0.005*NDEV(4)
      VYNOISE = 0.005*NDEV(5)
      VZNOISE = 0.005*NDEV(6)
      XO= XO + XNOISE
      YO= YO + YNOISE
      ZO = ZO + ZNOISE
      VXO = VXO + VXNOISE
      VYO = VYO + VYNOISE
      VZO = VZO + VZNOISE
      RAD = DSQRT(XO*XO + YO*YO + ZO*ZO)
      RD = (XO*VXO + YO*VYO + ZO*VZO)/RAD
      GCLAT = DASIN(ZO/DSQRT(XO*XO + YO*YO + ZO*ZO))
      RE = SMI/DSQRT(1.-EE*DCOS(GCLAT)**2)
      SSH = -.9*(RAD-RE)/RD
      SS = MIN(STEP,DABS(SSH))
      IF ((RAD-RE) .LT. 0000001) THEN
      MISLON = DATAN2(YO,XO) - OMEGA*TO
      MISLAT = DATAN(DTAN(GCLAT)/(1.-EE))
        ELSE
          GO TO 20
        ENDIF
      IF (TOTTIME - T .LT. 330.0) THEN
      RETURN
      ELSE
      WRITE(18,19)NUMRV,INDCLASS,MISLAT*RTD,MISLON*RTD,TOTTIME-T+LTIME
      ENDIF
19      FORMAT(1X,I2,2X,I1,2X,F10.5,3X,F10.5,3X,F10.5)
*
*
      IF ((TOTTIME - (T+STEP)) .GE. 0) THEN
        SS = STEP
        GOTO 10
      ELSE
        RETURN
      ENDIF
      ELSE
        SS = STEP
        GOTO 10
      ENDIF
```

END
.
.

Appendix G Sample Output of Impact Data

RV #	TGT CLASS	IMPACT LATITUDE	IMPACT LONGITUDE	TIME
1	2	38.56578	-121.19228	904.51490
1	2	38.44409	-121.24724	874.51490
1	2	38.34101	-121.29520	844.51490
1	2	38.43706	-121.21382	814.51490
1	2	38.53098	-121.18538	784.51490
1	2	38.27818	-121.25087	754.51490
1	2	38.39945	-121.27139	724.51490
1	2	38.47320	-121.19040	694.51490
1	2	38.39524	-121.22702	664.51490
1	2	38.43574	-121.23459	634.51490
1	2	38.42902	-121.26874	604.51490
1	2	38.44297	-121.20376	574.51490
1	2	38.52842	-121.22309	544.51490
1	2	38.42308	-121.23337	514.51490
1	2	38.38672	-121.25750	484.51490
1	2	38.39570	-121.21108	454.51490
1	2	38.37343	-121.25097	424.51490
1	2	38.40902	-121.25456	394.51490
1	2	38.45323	-121.24829	364.51490
1	2	38.43325	-121.21518	334.51490
2	4	33.58847	-117.08820	877.29653
2	4	33.57287	-117.13038	847.29653
2	4	33.59821	-117.13952	817.29653
2	4	33.55270	-117.16141	787.29653
2	4	33.58157	-117.03129	757.29653
2	4	33.50784	-117.12971	727.29653
2	4	33.47454	-117.17119	697.29653
2	4	33.58884	-117.12898	667.29653
2	4	33.56953	-117.12556	637.29653
2	4	33.59277	-117.08955	607.29653
2	4	33.56550	-117.10941	577.29653
2	4	33.59513	-117.06509	547.29653
2	4	33.55305	-117.16952	517.29653
2	4	33.50392	-117.16356	487.29653
2	4	33.57401	-117.12354	457.29653
2	4	33.58768	-117.08230	427.29653
2	4	33.53198	-117.15496	397.29653
2	4	33.51264	-117.17755	367.29653
2	4	33.54088	-117.15897	337.29653
3	1	37.42958	-121.91888	887.47881
3	1	37.32993	-122.02771	857.47881
3	1	37.31346	-122.06674	827.47881
3	1	37.47562	-121.95950	797.47881

3	1	37.41967	-121.98036	767.47881
3	1	37.40222	-122.02722	737.47881
3	1	37.31925	-122.06764	707.47881
3	1	37.38692	-121.97752	677.47881
3	1	37.39956	-121.97491	647.47881
3	1	37.29345	-122.03707	617.47881
3	1	37.32866	-121.99946	587.47881
3	1	37.37858	-121.99878	557.47881
3	1	37.43087	-121.99906	527.47881
3	1	37.36088	-121.98413	497.47881
3	1	37.35814	-122.01905	467.47881
3	1	37.36003	-121.99827	437.47881
3	1	37.46955	-122.00617	407.47881
3	1	37.41073	-122.00456	377.47881
3	1	37.38113	-122.04785	347.47881
4	3	39.01336	-121.38717	879.45049
4	3	39.07028	-121.29633	849.45049
4	3	39.12195	-121.20787	819.45049
4	3	39.15323	-121.20616	789.45049
4	3	39.05535	-121.24836	759.45049
4	3	38.97134	-121.36573	729.45049
4	3	39.06550	-121.29050	699.45049
4	3	39.02251	-121.31460	669.45049
4	3	39.02300	-121.36425	639.45049
4	3	39.09923	-121.21268	609.45049
4	3	39.04471	-121.32094	579.45049
4	3	39.09663	-121.27758	549.45049
4	3	39.06138	-121.27577	519.45049
4	3	39.12058	-121.22146	489.45049
4	3	39.07060	-121.31678	459.45049
4	3	39.10525	-121.24914	429.45049
4	3	39.12975	-121.21949	399.45049
4	3	39.09581	-121.23698	369.45049
4	3	39.05576	-121.30346	339.45049
5	3	37.54005	-121.97572	885.30898
5	3	37.50339	-122.00943	855.30898
5	3	37.57987	-122.05119	825.30898
5	3	37.56414	-122.04520	795.30898
5	3	37.51217	-121.97844	765.30898
5	3	37.48072	-122.05358	735.30898
5	3	37.53525	-121.99249	705.30898
5	3	37.58804	-122.03853	675.30898
5	3	37.49551	-122.06459	645.30898
5	3	37.51811	-122.05991	615.30898
5	3	37.50032	-121.98967	585.30898
5	3	37.56304	-122.05590	555.30898
5	3	37.48617	-122.01770	525.30898
5	3	37.52462	-122.02950	495.30898
5	3	37.47590	-122.08068	465.30898
5	3	37.50292	-122.05256	435.30898
5	3	37.52414	-122.06903	405.30898
5	3	37.54501	-121.99613	375.30898

5	3	37.55167	-121.99871	345.30898
6	2	33.44863	-117.44417	849.83636
6	2	33.42472	-117.53131	819.83636
6	2	33.42187	-117.51384	789.83636
6	2	33.47256	-117.42390	759.83636
6	2	33.42575	-117.53470	729.83636
6	2	33.43768	-117.49076	699.83636
6	2	33.37062	-117.60082	669.83636
6	2	33.35146	-117.55638	639.83636
6	2	33.41111	-117.53122	609.83636
6	2	33.45867	-117.46010	579.83636
6	2	33.33654	-117.57674	549.83636
6	2	33.35959	-117.53488	519.83636
6	2	33.42373	-117.51212	489.83636
6	2	33.44069	-117.45136	459.83636
6	2	33.42505	-117.49872	429.83636
6	2	33.35777	-117.54245	399.83636
6	2	33.34771	-117.56944	369.83636
6	2	33.42979	-117.46046	339.83636
7	2	32.36769	-117.10060	865.66261
7	2	32.35195	-117.16192	835.66261
7	2	32.46803	-117.07670	805.66261
7	2	32.34229	-117.15900	775.66261
7	2	32.34130	-117.06274	745.66261
7	2	32.40806	-117.10491	715.66261
7	2	32.40094	-117.13246	685.66261
7	2	32.47899	-117.14488	655.66261
7	2	32.34529	-117.19665	625.66261
7	2	32.37259	-117.14053	595.66261
7	2	32.40302	-117.14180	565.66261
7	2	32.38122	-117.16929	535.66261
7	2	32.46176	-117.12698	505.66261
7	2	32.38449	-117.16901	475.66261
7	2	32.44048	-117.11215	445.66261
7	2	32.42175	-117.12602	415.66261
7	2	32.45798	-117.10492	385.66261
7	2	32.38734	-117.14600	355.66261
8	4	38.97604	-121.26506	879.74100
8	4	39.03221	-121.29012	849.74100
8	4	39.00068	-121.35996	819.74100
8	4	38.98785	-121.31692	789.74100
8	4	39.01906	-121.30221	759.74100
8	4	38.96285	-121.33378	729.74100
8	4	39.06585	-121.22075	699.74100
8	4	39.03546	-121.24817	669.74100
8	4	39.01750	-121.26623	639.74100
8	4	38.97480	-121.32181	609.74100
8	4	38.99414	-121.29256	579.74100
8	4	39.09799	-121.19501	549.74100
8	4	39.07413	-121.22303	519.74100
8	4	39.13311	-121.20557	489.74100
8	4	39.05247	-121.26506	459.74100

8	4	39.04342	-121.26613	429.74100
8	4	39.04178	-121.26785	399.74100
8	4	39.04990	-121.25116	369.74100
8	4	39.06110	-121.26531	339.74100
9	2	34.28510	-117.27599	870.68068
9	2	34.33094	-117.20741	840.68068
9	2	34.42010	-117.21595	810.68068
9	2	34.44716	-117.17889	780.68068
9	2	34.36636	-117.27029	750.68068
9	2	34.44151	-117.19692	720.68068
9	2	34.32621	-117.21926	690.68068
9	2	34.34863	-117.22226	660.68068
9	2	34.36620	-117.25298	630.68068
9	2	34.33918	-117.26632	600.68068
9	2	34.34951	-117.17404	570.68068
9	2	34.42236	-117.20517	540.68068
9	2	34.33763	-117.24398	510.68068
9	2	34.35935	-117.23998	480.68068
9	2	34.37123	-117.23095	450.68068
9	2	34.32910	-117.24113	420.68068
9	2	34.39318	-117.19210	390.68068
9	2	34.35271	-117.24492	360.68068
9	2	34.36313	-117.21299	330.68068
10	1	34.25604	-118.44817	903.52696
10	1	34.17709	-118.63007	873.52696
10	1	34.25662	-118.56945	843.52696
10	1	34.22170	-118.51470	813.52696
10	1	34.15795	-118.58244	783.52696
10	1	34.20295	-118.51503	753.52696
10	1	34.23032	-118.49206	723.52696
10	1	34.12534	-118.58330	693.52696
10	1	34.24668	-118.47049	663.52696
10	1	34.22111	-118.54323	633.52696
10	1	34.19401	-118.56972	603.52696
10	1	34.15751	-118.58087	573.52696
10	1	34.22853	-118.54845	543.52696
10	1	34.14130	-118.59732	513.52696
10	1	34.15613	-118.60386	483.52696
10	1	34.23931	-118.48432	453.52696
10	1	34.18023	-118.56998	423.52696
10	1	34.21665	-118.50352	393.52696
10	1	34.23767	-118.52048	363.52696
10	1	34.21264	-118.51470	333.52696
11	3	32.33189	-117.17553	895.60749
11	3	32.53915	-117.06929	865.60749
11	3	32.38248	-117.13802	835.60749
11	3	32.36837	-117.13912	805.60749
11	3	32.38867	-117.10862	775.60749
11	3	32.42888	-117.05144	745.60749
11	3	32.50033	-117.09562	715.60749
11	3	32.39626	-117.11962	685.60749
11	3	32.43197	-117.09961	655.60749

11	3	32.48476	-117.14367	625.60749
11	3	32.42663	-117.15683	595.60749
11	3	32.49649	-117.05589	565.60749
11	3	32.41585	-117.15411	535.60749
11	3	32.38193	-117.16539	505.60749
11	3	32.45732	-117.09985	475.60749
11	3	32.41287	-117.11089	445.60749
11	3	32.44181	-117.11977	415.60749
11	3	32.38996	-117.15033	385.60749
11	3	32.37562	-117.15076	355.60749
12	3	34.43462	-120.31445	875.63499
12	3	34.47317	-120.29396	845.63499
12	3	34.38705	-120.36914	815.63499
12	3	34.46148	-120.29473	785.63499
12	3	34.49160	-120.28855	755.63499
12	3	34.48753	-120.32979	725.63499
12	3	34.31834	-120.43514	695.63499
12	3	34.44237	-120.38523	665.63499
12	3	34.40474	-120.31944	635.63499
12	3	34.40574	-120.37441	605.63499
12	3	34.47801	-120.32912	575.63499
12	3	34.33706	-120.44888	545.63499
12	3	34.43051	-120.35233	515.63499
12	3	34.43536	-120.38371	485.63499
12	3	34.40471	-120.35852	455.63499
12	3	34.42006	-120.36062	425.63499
12	3	34.42335	-120.35468	395.63499
12	3	34.41137	-120.36939	365.63499
12	3	34.41335	-120.36549	335.63499
13	1	35.30424	-118.97381	888.74963
13	1	35.24793	-118.99035	858.74963
13	1	35.19586	-119.01923	828.74963
13	1	35.18070	-118.99788	798.74963
13	1	35.19726	-119.07756	768.74963
13	1	35.25570	-119.00427	738.74963
13	1	35.18877	-118.99908	708.74963
13	1	35.20128	-119.02998	678.74963
13	1	35.16879	-119.05607	648.74963
13	1	35.21294	-119.06249	618.74963
13	1	35.18196	-119.03585	588.74963
13	1	35.17502	-119.07268	558.74963
13	1	35.18363	-119.04009	528.74963
13	1	35.21013	-119.07326	498.74963
13	1	35.23393	-118.99699	468.74963
13	1	35.23301	-119.04319	438.74963
13	1	35.17866	-119.07200	408.74963
13	1	35.18765	-119.05088	378.74963
13	1	35.20061	-119.04170	348.74963
14	1	33.48612	-118.06565	881.55443
14	1	33.52686	-118.01194	851.55443
14	1	33.59562	-118.04757	821.55443
14	1	33.56027	-118.01156	791.55443

14	1	33.54574	-118.04829	761.55443
14	1	33.47117	-118.03120	731.55443
14	1	33.42108	-118.14304	701.55443
14	1	33.54863	-118.02402	671.55443
14	1	33.48024	-118.00607	641.55443
14	1	33.46698	-118.05352	611.55443
14	1	33.49943	-118.04856	581.55443
14	1	33.51120	-118.03717	551.55443
14	1	33.48582	-118.01783	521.55443
14	1	33.51832	-118.00500	491.55443
14	1	33.48603	-118.06239	461.55443
14	1	33.54435	-118.00876	431.55443
14	1	33.55289	-118.02607	401.55443
14	1	33.46069	-118.04630	371.55443
14	1	33.51801	-118.03990	341.55443
15	4	38.29761	-121.41924	875.81569
15	4	38.18403	-121.43034	845.81569
15	4	38.31055	-121.40661	815.81569
15	4	38.33325	-121.42277	785.81569
15	4	38.30572	-121.37518	755.81569
15	4	38.25600	-121.48210	725.81569
15	4	38.22218	-121.41743	695.81569
15	4	38.28073	-121.42272	665.81569
15	4	38.24140	-121.39473	635.81569
15	4	38.40223	-121.37910	605.81569
15	4	38.35068	-121.37771	575.81569
15	4	38.24840	-121.42370	545.81569
15	4	38.26722	-121.39265	515.81569
15	4	38.32116	-121.41435	485.81569
15	4	38.29305	-121.42139	455.81569
15	4	38.32220	-121.40600	425.81569
15	4	38.28719	-121.43115	395.81569
15	4	38.29786	-121.41704	365.81569
15	4	38.24407	-121.44773	335.81569

Appendix II Source Code for Damage Expectancy Model

```
   Program nuclear_effects
*
*
* Programmed by Capt. Bob Bivins
*
* Statement of Problem
*
* This program estimates damage for predicted impact points of the
* reentry vehicles.  The data is written to a file called "PSTEST.SAS"
*
*
* Algorithm
*
* The algorithm is as follows:
*
* A.  THERMAL EFFECTS
*
* I.  Calculate normilization factors
*     a.  Test for condition of height of burst above below 4600 m
*         i.  calculate Pmax
*         ii. calculate Tmax
*
*     b.  Use atmospheric conditions program if HOB above 4600 m
*         i.  calculate Pmax
*         ii. calculate Tmax
*
*
* II  Calculate corresponding times and powers using normalized curves
*     a.  Calulate time vector, 21 values
*     b.  Calculate power vector, 21 values
*
*
* III. Calculate intensity at all time points
*      a.  Calulate intensity in a vacuum, spherical divergence
*      b.  Calculate intensity due to transmittance, atmospheric effects
*
*
* IV.  Calculate temperature at all time points
*      a.  Integrate using trapezoidal rule
*       b.  find max temp by sorting
*
*
* V.  Collect and report info
*     a.  Write data to file to be processes by SAS
*     b.  Print out key values
*
* B.  BLAST EFFECTS
*
* I.  Scale given info to 1Kt burst at sea level
```

```
*     a. Scale SR
*     b. Scale HOB
*
*
* II. Calculate Height of Triple Point
*     a. Find scaled height of triple point
*     b. Determine if target is in the Mach Stem
*
*
* III. If target if Mach Stem
*     a. Calculate overpressure on ground within Mach stem
*     b. Scale overpressure to target altitude
*
*
* IV. If target not in Mach Stem
*     a. Calculate overpressure and time of arrival for free air
*     b. Scale to burst altitude
*     c. Perform Ledsham-Pike correction on overpressure
*
*
* V. Use Rankine-Hugonoit to find other effects
*     a. Find shock velocity
*     b. Find wind velocity
*     c. Find air density behind shock wave
*     d. Find dynamic pressure
*
*
*
* C. Find the Probability of Survival
*
* I. Calculate the Probability of Survival from Blast effects
*     a. Given Sure Safe and Sure Kill Intensities for blast
*     b. Calculate median Intensity of 50% Probability of Survival
*     c. Calculate logrithmic slope
*     d. Use Intensity of blast (i.e. peak overpressure) to find Prob of Surv
*
* II. Calculate the Probability of Survival from Thermal effects
*     a. Given Sure Safe and Sure Kill Intensities for thermal
*     b. Calculate median Intensity of 50% Probability of Survival
*     c. Calculatae logrithmic slope
*     d. Use Intensity of thermal (i.e. maximum skin temp), find Prob of Surv
*
* III. Find Overall Probability of Survival
*     a. Use Probabilities of Survival for each effect
*     b. Find PK by : Pk = 1 - Ps
*
*
* Symbol Table
*
* VARIABLE     MEANING                        LOCATION
*
* YIELD        WEAPON YIELD IN KILOTONS         MAIN
* HOB          HEIGHT OF BURST                  MAIN
* RANGE        RANGE(TARGET TO BURST)           MAIN
* PMAX         POWER MAXIMUM                    NORM
* TMAX         TIME MAXIMUM                     NORM
* TTGT         TEMP AT TARGET ALTITUDE          NORM
```

```
* PTGT        PRESSURE AT TARGET ALTITUDE        NORM
* DENTGT      DENSITY AT TARGET ALTITUDE         NORM
* RHORATIO    RATIO OF TARGET DENSITY TO AIR     NORM
* TVECTOR     VECTOR OF 21 NORMALIZED TIMES      TP
* PVECTOR     VECTOR OF 21 NORMALIZED POWERS     TP
* TIME        VECTOR OF 21 REAL TIMES            TP
* POWER       VECTOR OF 21 REAL POWERS           TP
* IVAC        VECTOR OF 21 INTENSITIES IN VACUUM  INTEN
* SR          SLANT RANGE BETWEEN TARGET & BURST  INTEN
* TRANS       TRANSMITTANCE DUE TO ATMOS EFFECTS  INTEN
* Z           NATURAL log OF GROUND RANGE IN KM   INTEN
* INTENSE     VECTOR OF 21 ACTUAL INTENSITIES     INTEN
* TEMPAIR     TEMPERATURE OF AMBIENT AIR AT TARGET  SKINTEMP
* BETA        DENSITYXSPECIFIC HEAT X THICKNESS     SKINTEMP
* ALPHA       THERMAL ABSORPTION COEFFICIENT        SKINTEMP
* H           HEAT TRANSFER COEFFICENT              SKINTEMP
* J           VECTOR OF 21 INTERMEDIATE VALUES      SKINTEMP
* T           VECTOR OF 21 ACTUAL TEMPERATURES      SKINTEMP
* MAXTEMP     MAXIMUM SKIN TEMPERATURE              SKINTEMP
* X           Mass Integral                        MAIN
* PBRST       Standard pressure at burst altitude   MI
* DENBRST     Standard density at burst altitude    MI
* TBRST       Standard temp at burst altitude
* GEO         SIN theta                            MI
* CBRST       Speed of sound at burst alt
* R           Range in centimeters                 INTENSITY
* OVPISS      Sure Safe Intensity for overpressure   MAIN
* OVPISK      Sure Kill intensity for overpressure   MAIN
* THERMISS    Sure Safe Intensity for thermal        MAIN
* THERMISK    Sure Kill Intensity for thermal        MAIN
* ISS         Sure Safe Intensity                  PROBKILL
* ISK         Sure Kill Intensity                  PROBKILL
* PK          Probability of Kill                  PROBKILL
* A           Median Intensity of 50% Prob of Surv   PROBKILL
* B           logrithmic slope                     PROBKILL
* XX          Upper limit on integration of Normal   PROBKILL
* II          Intensity of effect at target        PROBKILL
* PSOVP       Probability of Survival from overpress  PROBSURV
* PSTHERM     Probability of Survival from thermal    PROBSURV
* PS          Overall Probability of Survival        PROBSURV
* ACTUALX     Xposition with respect to the burst     TP
*
*
*
*
      DOUBLE PRECISION YIELD,HOB,ACTUALX(10),THETA,TIME(21),POWER(21)
      DOUBLE PRECISION X,S,TTGT,PTGT,DENTGT,PMAX,TMAX,PBRST,TBRST,CBRST
      DOUBLE PRECISION DENBRST,SSR,SR,SHTP,SGR,SHOB,DELTAP,BURSTOVP
      DOUBLE PRECISION TGTOVP,SHOCKVEL,TGTC,WINDVEL,RHO,DYN
      DOUBLE PRECISION ISS,ISK,PK,A,B,XX,II,PSOVP,PSTHERM,PS
      DOUBLE PRECISION OVPISS,OVPISK,THERMISS,THERMISK,INTENSE(21)
      DOUBLE PRECISION MAXTEMP,TGTLAT,TGTLON,IMPLAT,IMPLON
      DOUBLE PRECISION SURV(10),TOTSURV,SUMSURV,DIFF,TTOIMP
      DOUBLE PRECISION POSIN,POSOUT,SEC,SECTODEC,DECSEC
      DOUBLE PRECISION MINUTES,MINTODEC,DECMIN,DEGREES
      Integer CELL,CLASS,RVNUM,M,N,O,TGT,READING,INDCLSS
      CHARACTER  TGTNAME*5
```

```
*
*
      Open(82,file='PSTEST.SAS',STATUS='UNKNOWN')
      Open(83,file='REALTGT.DAT',STATUS='UNKNOWN')
      Open(84,file='IMPEST.DAT',STATUS='UNKNOWN')
*
      YIELD = 550
      HOB = 2000
      CEP = 300
      DO 97 TGT = 1,200
      Read(83,*,END=26)CLASS,TGTLAT,TGTLON
*
*
      DO 98 READING = 1,5000
      Read(84,*,END=25)RVNUM,INDCLSS,IMPLAT,IMPLON,TTOIMP
*
      IF (CLASS .EQ. 1) THEN
        OVPISS = 0.5
        OVPISK = 5.5
*
        THERMISS = 477.15
        THERMISK = 852.15
      ELSE
      ENDIF
*
*
      IF (CLASS .EQ. 2) THEN
        OVPISS = 1.0
        OVPISK = 3.0
*
        THERMISS = 477.15
        THERMISK = 923.15
      ELSE
      ENDIF
*
*
      IF (CLASS .EQ. 3) THEN
        OVPISS = 10.0
        OVPISK = 45.0
*
        THERMISS = 650.15
        THERMISK = 1100.15
      ELSE
      ENDIF
*
*
      IF (CLASS .EQ. 4) THEN
        OVPISS = 5.0
        OVPISK = 10.0
*
        THERMISS = 550.15
        THERMISK = 775.15
      ELSE
      ENDIF
*
*
      Call QUADRATURE(CEP,TGTLAT,TGTLON,IMPLAT,IMPLON,ACTUALX,DIFF)
```

```
*
      IF (DIFF .GT. 35000) THEN
      GOTO 98
      ELSE
      ENDIF
      DO 99 CELL =1,10
*
      Call NORM(HOB,YIELD,PMAX,TMAX)
      Call TP(PMAX,TMAX,TIME,POWER)
      Call INTEN(POWER,HOB,INTENSE,ACTUALX,CELL)
      Call SKINTEMP(INTENSE,TIME,MAXTEMP,POWER)
      Call MI(HOB,ACTUALX,X,CELL)
      Call BURSTCOND(HOB,PBRST,TBRST,CBRST,DENBRST)
      Call SCALING(ACTUALX,YIELD,SSR,HOB,SR,CELL,PD,RBO)
      If (SR .LE. RBO) then
      PD = 1.000
      SUMSURV = 0.0
      GOTO 338
      endif
      Call SCALEHTP(YIELD,HOB,ACTUALX,SHTP,SGR,SHOB,SSR,CELL)
      Call MACHOVP(SHOB,SGR,SSR,PBRST,TGTOVP,YIELD)
      Call RKHUGO(TGTOVP,SHOCKVEL,WINDVEL,RHO,DYN)
*
*
*
      ISS = OVPISS
      ISK = OVPISK
      II = TGTOVP
*
      Call PROBKILL(ISS,ISK,II,PK)
      PSOVP = 1 - PK
*
      ISS = THERMISS
      ISK = THERMISK
      II = MAXTEMP
*
      Call PROBKILL(ISS,ISK,II,PK
      PSTHERM = 1 - PK
*
*
*
      Call PROBSURV(PSOVP,PSTHERM,PS)
*
      SURV(CELL) = PS
*
99    CONTINUE
*
      DO 76 CELL = 1,10
      SUMSURV = SUMSURV + SURV(CELL)
76    CONTINUE
*
      PD = 1 - SUMSURV/10.0
      SUMSURV = 0.0
338   IF (PD .GT. .005) THEN
      Write(82,101)RVNUM,TGT,CLASS,INDCLSS,DIFF,TTOIMP,PD
      PRINT 101,RVNUM,TGT,CLASS,INDCLSS,DIFF,TTOIMP,PD
101   FORMAT(1X,I3,4X,I3,4X,I3,4X,I3,5X,F10.4,3X,F9.4,3X,F9.4)
```

```
      ENDIF
*
98    CONTINUE
25    REWIND 84
97    CONTINUE
*
26    REWIND 83
*
      END
*
      end
*
*
*
* This subroutine calculates Pmax and Tmax.
*
*
      Subroutine NORM(HOB,YIELD,PMAX,TMAX)
*
      DOUBLE PRECISION PMAX,YIELD,TMAX,HOB
*
      If (HOB .LT. 4600) then
      PMAX = 1.34E13*YIELD**.56
      TMAX = .0417*YIELD**.44
        else
      PMAX = 1.5E13*YIELD**.59
      TMAX = .038*YIELD**.44
        endif
      end
*
* This subroutine calculates corresponding times and powers from
* a table of normalized power curve values.  It creates a vector
* for each variable, time and power, of 21 values.
*
*
      Subroutine TP(PMAX,TMAX,TIME,POWER)
*
      DOUBLE PRECISION PMAX,TMAX,TVECTOR(21),PVECTOR(21),TIME(21),POWER(21)
      Integer I,K,J
*
       Data (TVECTOR(I),I=1,11) /0.0,.5,1.0,1.5,2.0,2.5,3.0,3.5,4.0,4.5,5.0/
       Data (TVECTOR(I),I=12,21) /5.5,6.0,6.5,7.0,7.5,8.0,8.5,9.0,9.5,10.0/
       Data (PVECTOR(K),K=1,11) /.02,.67,1.0,.65,.4,.29,.22,.17,.14,.12,.1/
       Data (PVECTOR(K),K=12,19) /.089,.077,.069,.062,.056,.051,.046,.043/
      Data (PVECTOR(K),K=20,21) /.04,.037/
*
      DO 10 J=1,21
        TIME(J) = TVECTOR(J)*TMAX
        POWER(J) = PVECTOR(J)*PMAX
*
10      Continue
      end
*
* This subroutine calculates the actual intensity for each time
* point considering both spherical divergence and transmittance
* due to atmospheric conditions
*
```

```
*
      Subroutine INTEN(POWER,HOB,INTENSE,ACTUALX,CELL)
*
      DOUBLE PRECISION POWER(21),IVAC(21),SR,HOB,TRANS,Z,INTENSE(21)
      DOUBLE PRECISION ACTUALX(10)
      Integer I,K,CELL
*
      SR = (HOB**2 + ACTUALX(CELL)**2)**.5
      DO 20 I=1,21
       IVAC(I) = POWER(I)/(4*3.1415927*SR**2)
20     Continue
*
      Z = DLOG(SR/1000.0)
      TRANS = .8
*
      DO 30 K=1,21
       INTENSE(K) = IVAC(K)*TRANS
30     Continue
      end
*
*
* This subroutine calculates the skin temperature at each point in
* time and returns the maximum value attained.
*
*
      Subroutine SKINTEMP(INTENSE,TIME,MAXTEMP,POWER)
*
      DOUBLE PRECISION TEMPAIR,BETA,ALPHA,H,INTENSE(21),TIME(21),J(21),T(21)
      DOUBLE PRECISION M(21),POWER(21),POWERMAX,MAXTEMP
      Integer I,K
*
      TEMPAIR = 288.1
      BETA = 2770*1005*.0026
      ALPHA = .5
      H = 71.75
      DO 40 I=1,21
       J(I) = INTENSE(I)*DEXP(H*TIME(I)/BETA)
40     Continue
*
      T(1) = TEMPAIR
      M(1) = 0
      DO 50 K=2,21
     M(K) = M(K-1) + .5*(TIME(K)-TIME(K-1))*(J(K-1)+J(K))
      T(K) = T(1) + (ALPHA/BETA)*DEXP(-H*TIME(K)/BETA)*M(K)
50     Continue
*
      MAXTEMP = 0
      Do 70 Q=1,21
      If (T(Q) .GT. MAXTEMP) then
      MAXTEMP = T(Q)
      endif
70     Continue
      end
*
*
*
*
```

```
* Calculates Mass Integral.
*
      Subroutine MI(HOB,ACTUALX,X,CELL)
*
      DOUBLE PRECISION HOB,ACTUALX(10),X,TBRST,TTGT,PBRST,PTGT,DENBRST
      DOUBLE PRECISION DENTGT,SR,GEO,DVERT
      Integer CELL
*
      TBRST = 288.1 - 0.006545*HOB
      TTGT = 288.15
      PBRST = 1.013E5*(288.15/TBRST)**(-5.22)
      PTGT = 1.013E5*(288.15/TTGT)**(-5.22)
      DENBRST = .003484*PBRST/TBRST
      DENTGT = .003484*PTGT/TTGT
      SR = (HOB**2 + ACTUALX(CELL)**2)**.5
      GEO = DSIN(HOB/SR)
      X = (1/GEO)*.1019368*(PBRST - PTGT)
      X = .1*X
      end
*
*
*
*
      Subroutine BURSTCOND(HOB,PBRST,TBRST,CBRST,DENBRST)
      DOUBLE PRECISION HOB,PBRST,TBRST,CBRST,DENBRST
*
      TBRST = 288.1 - 0.006545*HOB
      PBRST = 14.7*(288.15/TBRST)**(-5.22)
      DENBRST = 0.003484*(6891.1565*PBRST/TBRST)
      CBRST = (401.9*TBRST)**.5
      end
*
*
*
      Subroutine SCALING(ACTUALX,YIELD,SSR,HOB,SR,CELL,PD,RBO)
*
      DOUBLE PRECISION ACTUALX(10),SSR,YIELD,HOB,SR,PTGT,RBO
      Integer CELL
*
      SR = SQRT(HOB**2 + ACTUALX(CELL)**2)
      SSR = SR*((1.0/YIELD)**(1.0/3.0))
      END
*
*
*
      Subroutine SCALEHTP(YIELD,HOB,ACTUALX,SHTP,SGR,SHOB,SSR,CELL)
*
      DOUBLE PRECISION YIELD,HOB,SHOB,SCALEOTP,CP,SHTP,SGR,SSR,ACTUALX(
      Integer UV,CELL
*
      SGR = ACTUALX(CELL)*((1.0/YIELD)**(1.0/3.0))
      SHOB = HOB/(YIELD**(1.0/3.0))
*
      If (SHOB .LE. 1.5) then
      SHTP = 0
      SCALEOTP = 0
      return
```

```
      endif
      If (SHOB .GT. 1.5 .AND. SHOB .LE. 600) then
      CP = .02754 + (2.524/SHOB) + (1085.0/(SHOB**2))
     + - (43720.0/(SHOB**3)) + (585000.0/(SHOB**4))
     + - (2.731E6/(SHOB**5))
      SCALEOTP = 95*(DEXP(SHOB/175.0) -1.0)
*
*
      endif
      If (SHOB .GT. 600 .AND. SHOB .LE. 800) then
      CP = 0.04
      SCALEOTP = 95*DEXP(SHOB/175.0)
      endif
      If (SHOB .GT. 800) then
      SHTP = 0
      return
      endif
      If (SGR .LT. SCALEOTP) then
      SHTP = 0
      else
      SHTP = CP*SCALEOTP*(((SGR/SCALEOTP) -1.0)**1.6)
      endif
      END
*
*
      Subroutine MACHOVP(SHOB,SGR,SSR,PBRST,TGTOVP,YIELD)
*
      DOUBLE PRECISION
XX,SHOB,SGR,GAMMA,BETA,ALPHA1,DELTA,DELTAP0,SSR,PBRST
      DOUBLE PRECISION DELTAP90,DELTAPB,DELTAPA,DELTAP,YIELD,TGTOVP
*

      XX = DSQRT((SHOB**2) + (SGR**2))
      If (XX .GE. 4500) then
      TGTOVP = 0.0
      return
      endif
*
      if (SGR .LE. 100 .OR. SHOB .LE. 100) THEN
      DELTA = 0.0
      else
      DELTA = DATAN(SHOB/SGR)
      endif
*
      GAMMA = DEXP(.1826*(DLOG(XX))**4 - 4.36786*(DLOG(XX))**3 +
     + 38.6017*(DLOG(XX))**2 - 149.59*DLOG(XX) + 216.26)
      BETA = DEXP(.25192*(DLOG(XX))**4 - 5.8741*(DLOG(XX))**3 +
     + 50.298*(DLOG(XX))**2 - 185.95*DLOG(XX) + 248.8)
      ALPHA1 = DEXP(.3549*(DLOG(XX))**3 - 6.7133*(DLOG(XX))**2 +
     + 41.468*DLOG(XX) -82.819)
      DELTAP0 = .001*DEXP(31.3*XX**(-.2136))
      DELTAP90 = .01*DEXP(40.3*XX**(-.295))
      DELTAPB = ((COS(DELTA))**(2*BETA))*((SIN(DELTA))**ALPHA1)*DEXP(GAMMA)
      DELTAPA = DELTAP90 - (DELTAP90 - DELTAP0)*(COS(DELTA))**2
      TGTOVP = DELTAPA + DELTAPB
      END
*
```

```
*
*
      Subroutine RKHUGO(TGTOVP,SHOCKVEL,WINDVEL,RHO,DYN)
*
      DOUBLE PRECISION TGTOVP,SHOCKVEL,WINDVEL,RHO,DYN
*
      SHOCKVEL = 340.275*(1.+((6*TGTOVP)/(7*14.7)))**.5
      WINDVEL=(5*TGTOVP/(7*14.7))*340.275/(1+((6*TGTOVP)/(7*14.7)))**.5
      RHO = 1.2250233*((7.+((6*TGTOVP)/14.7))/(7.+(TGTOVP/14.7)))
      DYN = (5.0/2.0)*((TGTOVP**2)/(7*14.7 + TGTOVP))
      end
*
*
*
* This subroutine will calculate a Probability of Kill.
*
*
      Subroutine PROBKILL(ISS,ISK,II,PK)
*
      DOUBLE PRECISION ISS,ISK,PK,A,B,XX,II
*
      If (II .LE. .5*ISS) then
        PK = 0
      RETURN
      endif
*
      A = .5*DLOG(ISK*ISS)
      B = DLOG(ISK/ISS)/(2.0*2.054)
      XX = (DLOG(II) - A)/B
*
      If (XX .GE. 0.0) then
      PK = 1 -.5*(1 + .196854*XX + .115194*XX**2 + .000344*XX**3 +
     + .019527*XX**4)**(-4)
      else
      XX = ABS(XX)
      PK = .5*(1 + .196854*XX + .115194*XX**2 + .000344*XX**3 +
     + .019527*XX**4)**(-4)
      endif
      end
*
*
*
* This subroutine calculates a Probability of Survival.
*
*
      Subroutine PROBSURV(PSOVP,PSTHERM,PS)
*
      DOUBLE PRECISION PSOVP,PSTHERM,PS
*
*
      PS = PSOVP*PSTHERM
```

```
* This Subroutine uses an equal probability cell quadrature
* to calculate the Ground RANGE from the detonation pt to the
* target. The Ground RANGE from the centroid of each of
* the equal probability cells is then used in other subroutines
* to calculate the nuclear effects on the target.
*
*
      Subroutine QUADRATURE(CEP,TGTLAT,TGTLON,IMPLAT,IMPLON,ACTUALX,DIFF)
*
      DOUBLE PRECISION RHOCEP(10),RHOTHETA(10),CEP,RCEP(10),ACTUALX(10)
      DOUBLE PRECISION DIFF,TGTLAT,TGTLON,IMPLAT,IMPLON
      DOUBLE PRECISION TGTLATRAD,TGTLONRAD,IMPLATRAD,IMPLONRAD
      DOUBLE PRECISION TGTLONDEC,TGTLATDEC
      Integer B,C,D
*
      DATA (RHOCEP(B),B=1,10)/0,4*.710767,5*1.50888/
       DATA (RHOTHETA(C),C=1,10)/0,.7071,2*-.7071,.7071,1,.309,2*-.809,.309/
*
*
*
      TGTLATDEC = TGTLAT
      TGTLONDEC = TGTLON
      IMPLATRAD = IMPLAT/57.29578
      IMPLONRAD = IMPLON/57.29578
      TGTLATRAD = TGTLATDEC/57.29578
      TGTLONRAD = TGTLONDEC/57.29578
*
     DIFF=1852*60*DACOS(DSIN(TGTLATRAD)*DSIN(IMPLATRAD)+DCOS(TGTLATRAD)*
    + DCOS(IMPLATRAD)*DCOS(IMPLONRAD-TGTLONRAD))
      DIFF = DIFF*57.29578
      POS = DIFF/CEP
*
      DO 15 D=1,10
*
      RCEP(D)=DSQRT(RHOCEP(D)**2+POS**2-2*RHOCEP(D)*POS*RHOTHETA(D))
      ACTUALX(D) = RCEP(D)*CEP
*
*
15     CONTINUE
      End
*
*
*
```

Appendix I Simulated Attack

RV #	Launch Latitude	Launch Longitude	Target Latitude	Target Longitude	Target Class	Target or Nearest City
1	56.4000	74.0005	38.4000	-121.2354	2	McClellan AFB
2	55.3333	40.3135	33.5429	-117.1408	4	March AFB, GWEN site
3	56.4000	74.0005	34.0149	-118.3321	1	Los Angeles, California
4	55.3333	40.3135	39.0812	-121.2642	3	Beale AFB, TankerWing
5	56.4000	74.0005	37.2248	-120.3400	3	Castle AFB, Bombers
6	55.3333	40.3135	33.4219	-117.4929	2	Tustin Marine Corps AS
7	56.4000	74.0005	32.4200	-117.1242	2	U.S. Naval AS North Is.
8	55.3333	40.3135	39.0559	-121.2502	4	Beale AFB, radar site
9	56.4000	74.0005	34.3518	-117.2300	2	George AFB
10	55.3333	40.3135	33.2615	-117.5601	1	Anaheim, California
11	56.4000	74.0005	34.0542	-117.1400	3	Norton AFB, BMO
12	55.3333	40.3135	33.5436	-118.0339	1	Cerritos, California
13	56.4000	74.0005	34.0834	-118.1132	1	Glendale, California
14	56.4000	74.0005	38.0631	-122.1518	1	Vallejo, California
15	56.4000	74.0005	38.2933	-121.4101	4	Davis, EW radar site

Appendix J Bayesian Processor

```
*
*
      PROGRAM DETERMTGT
*
      REAL PROBD,PD(15),ESTTIME,MOE,DIST,TIME
      REAL PROB1(0:15),MARG,COND(0:15),BIN(0:15),THETA(0:15)
      REAL PROB2(0:15),PROB3(0:15),PROB4(0:15)
      REAL EPOST(4),STDEVPOST(4),VARPOST(4)
      INTEGER CLASS1,CLASS2,CLASS3,CLASS4,RV,L,M,I,J,TGT,CLASS,CLASSVECT(15)
      INTEGER P,Q,X,K,HIT,AIMCLASS,CITY,OTHMIL,STRATMIL,CCC,INTENDVECT(15)
      INTEGER C1,C2,C3,C4,F
*
      OPEN(10,FILE='EXPERDAT.SAS',STATUS = 'NEW')
*
      OPEN(11,FILE='PSTEST.SAS',STATUS = 'OLD')
*
*
      ESTTIME = 900.0
      DATA (CLASSVECT(M),M=1,15) 15*1
      DATA (PD(J),J =1,15) 15*0.0
      DATA (THETA(J),J=0,15) 16*0.0
      DATA (PROB1(L),L=0,15) 6*.0018,.05,.15,.40,.15,.05,5*.0018
      DATA (PROB2(L),L=0,15) 16*.0625
      DATA (PROB3(L),L=0,15) 16*.0625
      DATA (PROB4(L),L=0,15)/16*.0625
      DATA (BIN(K), K=0,9)/1,15,105,455,1365,3003,5005,2*6435,5005/
      DATA (BIN(K), K=10,15)/3003,1365,455,105,15,1/
      DATA (THETA(J), J=0,7) 0.0,.06667,.13333,.2,.26667,.33333,.4,.46667
      DATA (THETA(J), J=8,15) .53333,.6,.66667,.73333,.8,.86667,.93333,1.0
*
*
      DO 5 F = 1,15
      CLASSVECT(F) = 1
5     CONTINUE
*
      DO 10 P = 1,19
      DO 20 I=1,10000
      READ (11,*,END=25)RV,TGT,CLASS,AIMCLASS,DIST,TIME,PROBD
*
      INTENDVECT(RV) = AIMCLASS
*
      IF (TIME .LE. ESTTIME .AND. TIME .GT. ESTTIME-30.0) THEN
        J =RV
        IF (PROBD .GE. PD(J)) THEN
           PD(J) = PROBD
           CLASSVECT(J) = CLASS
        ENDIF
      ENDIF
20    CONTINUE
25    REWIND 11
      DO 30 L =1,15
      IF (CLASSVECT(L) .EQ. 1) THEN
      CLASS1 = CLASS1 + 1
```

```
      ENDIF
*
      IF (CLASSVECT(L) .EQ. 2) THEN
      CLASS2 = CLASS2 + 1
      ENDIF
*
      IF (CLASSVECT(L) .EQ. 3) THEN
      CLASS3 = CLASS3 + 1
      ENDIF
      IF (CLASSVECT(L) .EQ. 4) THEN
      CLASS4 = CLASS4 + 1
      ENDIF
*
      IF (INTENDVECT(L) .EQ. 1) THEN
      CITY = CITY + 1
      ENDIF
*
      IF (INTENDVECT(L) .EQ. 2) THEN
      OTHMIL = OTHMIL + 1
      ENDIF
*
      IF (INTENDVECT(L) .EQ. 3) THEN
      STRATMIL = STRATMIL + 1
      ENDIF
*
      IF (INTENDVECT(L) .EQ. 4) THEN
      CCC = CCC + 1
      ENDIF
*
*
30    CONTINUE
      PRINT*
      C1 = CLASS1
      C2 = CLASS2
      C3 = CLASS3
      C4 = CLASS4
      MOE = REAL(MIN(C1,CITY)+MIN(C2,OTHMIL)+MIN(C3,STRATMIL)+MIN(C4,CCC))/15
      PRINT*,'MOE IS:',MOE
      PRINT*
      PRINT*,'AT',ESTTIME,'SECONDS BEFORE IMPACT'
      PRINT*,'THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED'
      PRINT*,'FOR EACH RESPECTIVE CLASS'
      PRINT*
      PRINT*,'CLASS 1, CITY INDUSTRIAL:',CLASS1
      PRINT*,'CLASS 2, OTHER MILITARY:',CLASS2
      PRINT*,'CLASS 3, STRATEGIC MILITARY:',CLASS3
      PRINT*,'CLASS 4, COMMAND & CONTROL,COMM:',CLASS4
      PRINT*
*
      DO 35 K = 1,4
         IF (K .EQ. 1) THEN
*     PRINT*,'THE NEW DISTRIBUTION FOR CITY INDUSTRIAL IS'
*     PRINT*,'-----------------------------------------------'
           HIT = CLASS1
      ENDIF
*
         IF (K .EQ. 2) THEN
```

```
*     PRINT*,'THE NEW DISTRIBUTION FOR OTHER MILITARY IS'
*     PRINT*,'-----------------------------------------------'
         HIT = CLASS2
       ENDIF
*
       IF (K .EQ. 3) THEN
*     PRINT*,'THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS'
*     PRINT*,'-----------------------------------------------'
         HIT = CLASS3
       ENDIF
*
       IF (K .EQ. 4) THEN
*     PRINT*,'THE NEW DISTRIBUTION FOR COMMAND AND CONTROL IS'
*     PRINT*,'-----------------------------------------------'
         HIT = CLASS4
       ENDIF
*
*
      MARG = 0.0
      DO 36 I = 0,15
      IF (HIT.EQ.0.AND.THETA(I).EQ.0.0.OR.HIT.EQ.15.AND.THETA(I).EQ.1.0) THEN
      IF (K .EQ. 1) THEN
      MARG = MARG + PROB1(I)
      ENDIF
*
      IF (K .EQ. 2) THEN
      MARG = MARG + PROB2(I)
      ENDIF
*
      IF (K .EQ. 3) THEN
      MARG = MARG + PROB3(I)
      ENDIF
*
      IF (K .EQ. 4) THEN
      MARG = MARC + PROB4(I)
      ENDIF
*
      GOTO 36
      ENDIF
*
      IF (K .EQ. 1) THEN
     MARG=MARG+PROB1(I)*BIN(HIT)*THETA(I)**HIT*(1.0-THETA(I))**(15-HIT)
      ENDIF
*
      IF (K .EQ. 2) THEN
     MARG=MARG+PROB2(I)*BIN(HIT)*THETA(I)**HIT*(1.0-THETA(I))**(15-HIT)
      ENDIF
*
      IF (K .EQ. 3) THEN
     MARG=MARG+PROB3(I)*BIN(HIT)*THETA(I)**HIT*(1.0-THETA(I))**(15-HIT)
      ENDIF
*
      IF (K .EQ. 4) THEN
     MARG=MARG+PROB4(I)*BIN(HIT)*THETA(I)**HIT*(1.0-THETA(I))**(15-HIT)
      ENDIF
*
36    CONTINUE
```

```
*
      DO 37 J = 0,15
      IF (HIT.EQ.0.AND.THETA(J).EQ.0.0 OR HIT.EQ.15.AND.THETA(J).EQ.1.0) THEN
      IF (K .EQ. 1) THEN
      PROB1(J) = PROB1(J)/MARG
      GOTO 371
      ENDIF
      IF (K .EQ. 2) THEN
      PROB2(J) = PROB2(J)/MARG
      GOTO 372
      ENDIF
*
      IF (K .EQ. 3) THEN
      PROB3(J) = PROB3(J)/MARG
      GOTO 373
      ENDIF
*
      IF (K .EQ. 4) THEN
      PROB4(J) = PROB4(J)/MARG
      GOTO 374
      ENDIF
*
      ENDIF
*
*
      IF (K .EQ. 1) THEN
      PROB1(J)=PROB1(J)*BIN(HIT)*THETA(J)**HIT*(1.0-THETA(J))**(15-HIT)/MARG
*      PRINT*,'NEW POSTERIOR FOR THETA ',THETA(J),' IS',PROB1(J)
371    WRITE(10,*)ESTTIME,MOE,K,THETA(J),PROB1(J)
      ENDIF
*
      IF (K .EQ. 2) THEN
      PROB2(J)=PROB2(J)*BIN(HIT)*THETA(J)**HIT*(1.0-THETA(J))**(15-HIT)/MARG
*      PRINT*,'NEW POSTERIOR FOR THETA ',THETA(J),' IS',PROB2(J)
372    WRITE(10,*)ESTTIME,MOE,K,THETA(J),PROB2(J)
      ENDIF
*
      IF (K .EQ. 3) THEN
      PROB3(J)=PROB3(J)*BIN(HIT)*THETA(J)**HIT*(1.0-THETA(J))**(15-HIT)/MARG
*      PRINT*,'NEW POSTERIOR FOR THETA ',THETA(J),' IS',PROB3(J)
373    WRITE(10,*)ESTTIME,MOE,K,THETA(J),PROB3(J)
      ENDIF
*
      IF (K .EQ. 4) THEN
      PROB4(J)=PROB4(J)*BIN(HIT)*THETA(J)**HIT*(1.0-THETA(J))**(15-HIT)/MARG
*      PRINT*,'NEW POSTERIOR FOR THETA ',THETA(J),' IS',PROB4(J)
374    WRITE(10,*)ESTTIME,MOE,K,THETA(J),PROB4(J)
      ENDIF
*
37     CONTINUE
*
*
*      PRINT*,'**************************************************'
*      PRINT*
*      PRINT*
38     CONTINUE
      ESTTIME = ESTTIME + 30.0
```

```
.
      DO 40 I = 1,15
      PD(I) = 0.0
40    CONTINUE
.
      CLASS1 = 0
      CLASS2 = 0
      CLASS3 = 0
      CLASS4 = 0
      CITY = 0
      OTHMIL = 0
      STRATMIL = 0
      CCC = 0
      C1 = 0
      C2 = 0
      C3 = 0
      C4 = 0
.
.
      IF (P .EQ. 10) THEN
      DO 50 Q = 1,4
        DO 60 F = 0,15
         IF (Q .EQ. 1) THEN
         EPOST(Q) = EPOST(Q) + THETA(F)*PROB1(F)
         ENDIF
.
         IF (Q .EQ. 2) THEN
         EPOST(Q) = EPOST(Q) + THETA(F)*PROB2(F)
         ENDIF
.
         IF (Q .EQ. 3) THEN
         EPOST(Q) = EPOST(Q) + THETA(F)*PROB3(F)
         ENDIF
.
         IF (Q .EQ. 4) THEN
         EPOST(Q) = EPOST(Q) + THETA(F)*PROB4(F)
         ENDIF
.
60    CONTINUE
50    CONTINUE
.
      PRINT*,'AT 6 MINUTES PRIOR TO IMPACT THE FOLLOWING TABLE OF'
      PRINT*,'  RESULTS EXIST: (90% CONFIDENCE LEVEL)'
      PRINT*,'*****************************************************'
      PRINT*
      PRINT*,'    CLASS   LOWER BOUND    EXPECTED VALUE    UPPER BOUND'
     PRINT*,'--------------------------------------------------------'
      PRINT*
      PRINT*,'1 CITY INDUSTRIAL',                    EPOST(1)
      PRINT*,'2 OTHER MILITARY',                      EPOST(2)
      PRINT*,'3 STRATEGIC MILITARY',                    EPOST(3)
      PRINT*,'4 CRITICAL CCC',                       EPOST(4)
      PRINT*
.
      ENDIF
10    CONTINUE
      END
```

Appendix K. Improved Radar Posterior Probabilities

```
MOE IS: 0.600000

AT  900.0000   SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY INDUSTRIAL:            11
CLASS 2, OTHER MILITARY:              1
CLASS 3, STRATEGIC MILITARY:          1
CLASS 4, COMMAND & CONTROL,COMM:      2

THE NEW DISTRIBUTION FOR CITY INDUSTRIAL IS
------ --- ------------ ------ --------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  3.6206621E-12
NEW POSTERIOR FOR THETA =  0.1333300      IS  5.5085079E-09
NEW POSTERIOR FOR THETA =  0.2000000      IS  3.4602081E-07
NEW POSTERIOR FOR THETA =  0.2666700      IS  5.7852953E-06
NEW POSTERIOR FOR THETA =  0.3333300      IS  4.5991150E-05
NEW POSTERIOR FOR THETA =  0.4000000      IS  6.2283739E-03
NEW POSTERIOR FOR THETA =  0.4666700      IS  6.3580461E-02
NEW POSTERIOR FOR THETA =  0.5333300      IS  0.4317132
NEW POSTERIOR FOR THETA =  0.6000000      IS  0.3192527
NEW POSTERIOR FOR THETA =  0.6666700      IS  0.1635412
NEW POSTERIOR FOR THETA =  0.7333300      IS  6.8802261E-03
NEW POSTERIOR FOR THETA =  0.8000000      IS  5.6692031E-03
NEW POSTERIOR FOR THETA =  0.8666700      IS  2.7009405E-03
NEW POSTERIOR FOR THETA =  0.9333300      IS  3.8152363E-04
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
*****************************************************

THE NEW DISTRIBUTION FOR OTHER MILITARY IS
------------------------------------------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  0.4439132
NEW POSTERIOR FOR THETA =  0.1333300      IS  0.3145973
NEW POSTERIOR FOR THETA =  0.2000000      IS  0.1538737
NEW POSTERIOR FOR THETA =  0.2666700      IS  6.0679339E-02
NEW POSTERIOR FOR THETA =  0.3333300      IS  1.9975688E-02
NEW POSTERIOR FOR THETA =  0.4000000      IS  5.4834252E-03
NEW POSTERIOR FOR THETA =  0.4666700      IS  1.2297834E-03
NEW POSTERIOR FOR THETA =  0.5333300      IS  2.1677466E-04
NEW POSTERIOR FOR THETA =  0.6000000      IS  2.8175078E-05
NEW POSTERIOR FOR THETA =  0.6666700      IS  2.4379590E-06
NEW POSTERIOR FOR THETA =  0.7333300      IS  1.1798097E-07
NEW POSTERIOR FOR THETA =  0.8000000      IS  2.2928939E-09
NEW POSTERIOR FOR THETA =  0.8666700      IS  8.5058557E-12
NEW POSTERIOR FOR THETA =  0.9333300      IS  5.5967501E-16
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
*****************************************************
```

```
THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS
-----------------------------------------------
NEW POSTERIOR FOR THETA   0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA   6.6670001E-02  IS  0.4439132
NEW POSTERIOR FOR THETA   0.1333300      IS  0.3145973
NEW POSTERIOR FOR THETA   0.2000000      IS  0.1538737
NEW POSTERIOR FOR THETA   0.2666700      IS  6.0679339E-02
NEW POSTERIOR FOR THETA   0.3333300      IS  1.9975688E-02
NEW POSTERIOR FOR THETA   0.4000000      IS  5.4834252E-03
NEW POSTERIOR FOR THETA   0.4666700      IS  1.2297834E-03
NEW POSTERIOR FOR THETA   0.5333300      IS  2.1677466E-04
NEW POSTERIOR FOR THETA   0.6000000      IS  2.8175078E-05
NEW POSTERIOR FOR THETA   0.6666700      IS  2.4379590E-06
NEW POSTERIOR FOR THETA   0.7333300      IS  1.1798097E-07
NEW POSTERIOR FOR THETA   0.8000000      IS  2.2928939E-09
NEW POSTERIOR FOR THETA   0.8666700      IS  8.5058557E-12
NEW POSTERIOR FOR THETA   0.9333300      IS  5.5967501E-16
NEW POSTERIOR FOR THETA    1.000000      IS  0.0000000E+00
**************************************************


THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS
-----------------------------------------------
NEW POSTERIOR FOR THETA = 0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA   6.6670001E-02  IS  0.2037163
NEW POSTERIOR FOR THETA   0.1333300      IS  0.3109293
NEW POSTERIOR FOR THETA   0.2000000      IS  0.2471365
NEW POSTERIOR FOR THETA   0.2666700      IS  0.1417581
NEW POSTERIOR FOR THETA   0.3333300      IS  6.4164929E-02
NEW POSTERIOR FOR THETA   0.4000000      IS  2.3485141E-02
NEW POSTERIOR FOR THETA   0.4666700      IS  6.9131334E-03
NEW POSTERIOR FOR THETA   0.5333300      IS  1.5915751E-03
NEW POSTERIOR FOR THETA = 0.6000000      IS  2.7151196E-04
NEW POSTERIOR FOR THETA = 0.6666700      IS  3.1325319E-05
NEW POSTERIOR FOR THETA = 0.7333300      IS  2.0843454E-06
NEW POSTERIOR FOR THETA = 0.8000000      IS  5.8921863E-08
NEW POSTERIOR FOR THETA = 0.8666700      IS  3.5520284E-10
NEW POSTERIOR FOR THETA = 0.9333300      IS  5.0335360E-14
NEW POSTERIOR FOR THETA =  1.000000      IS  0.0000000E+00
**************************************************
```

MOE IS: 0.8666667

AT 600.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 7
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 1
CLASS 4, COMMAND & CONTROL/COMM: 3

THE NEW DISTRIBUTION FOR CITY INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.1333300 IS 1.1954157E-24
NEW POSTERIOR FOR THETA = 0.2000000 IS 1.4336356E-14
NEW POSTERIOR FOR THETA = 0.2666700 IS 1.3369030E-08
NEW POSTERIOR FOR THETA = 0.3333300 IS 4.6628513E-05
NEW POSTERIOR FOR THETA = 0.4000000 IS 8.5683756E-02
NEW POSTERIOR FOR THETA = 0.4666700 IS 0.6718776
NEW POSTERIOR FOR THETA = 0.5333300 IS 0.2418049
NEW POSTERIOR FOR THETA = 0.6000000 IS 5.8701308E-04
NEW POSTERIOR FOR THETA = 0.6666700 IS 3.9518266E-08
NEW POSTERIOR FOR THETA = 0.7333300 IS 3.4373213E-15
NEW POSTERIOR FOR THETA = 0.8000000 IS 1.3351663E-23
NEW POSTERIOR FOR THETA = 0.8666700 IS 7.6493946E-37
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 2.2475454E-15
NEW POSTERIOR FOR THETA = 0.1333300 IS 1.0834739E-05
NEW POSTERIOR FOR THETA = 0.2000000 IS 6.1342474E-02
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.7505540
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.1858960
NEW POSTERIOR FOR THETA = 0.4000000 IS 2.1951352E-03
NEW POSTERIOR FOR THETA = 0.4666700 IS 1.6427758E-06
NEW POSTERIOR FOR THETA = 0.5333300 IS 7.3555537E-11
NEW POSTERIOR FOR THETA = 0.6000000 IS 1.3633678E-16
NEW POSTERIOR FOR THETA = 0.6666700 IS 4.9150286E-24
NEW POSTERIOR FOR THETA = 0.7333300 IS 8.4330360E-34
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

```
THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS
----------------------------------------------
NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 0.9534649
NEW POSTERIOR FOR THETA = 0.1333300     IS 4.6506215E-02
NEW POSTERIOR FOR THETA = 0.2000000     IS 2.8965404E-05
NEW POSTERIOR FOR THETA = 0.2666700     IS 1.5109672E-09
NEW POSTERIOR FOR THETA = 0.3333300     IS 1.0223838E-14
NEW POSTERIOR FOR THETA = 0.4000000     IS 9.0909880E-21
NEW POSTERIOR FOR THETA = 0.4666700     IS 8.6150939E-28
NEW POSTERIOR FOR THETA = 0.5333300     IS 5.7439533E-36
NEW POSTERIOR FOR THETA = 0.6000000     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.6666700     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.7333300     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300     IS 0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000     IS 0.0000000E+00
*****************************************************


THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS
-----------------------------------------------
NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 1.0336556E-07
NEW POSTERIOR FOR THETA = 0.1333300     IS 5.0042503E-02
NEW POSTERIOR FOR THETA = 0.2000000     IS 0.8353939
NEW POSTERIOR FOR THETA = 0.2666700     IS 0.1139450
NEW POSTERIOR FOR THETA = 0.3333300     IS 6.1818527E-04
NEW POSTERIOR FOR THETA = 0.4000000     IS 2.3118857E-07
NEW POSTERIOR FOR THETA = 0.4666700     IS 6.6194559E-12
NEW POSTERIOR FOR THETA = 0.5333300     IS 1.2027955E-17
NEW POSTERIOR FOR THETA = 0.6000000     IS 8.5295881E-25
NEW POSTERIOR FOR THETA = 0.6666700     IS 9.7386190E-34
NEW POSTERIOR FOR THETA = 0.7333300     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700     IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300     IS 0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000     IS 0.0000000E+00
*****************************************************
```

MOE IS: 0.933333

AT 480.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY INDUSTRIAL: 6
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 2
CLASS 4, COMMAND & CONTROL,COMM: 3

THE NEW DISTRIBUTION FOR CITY INDUSTRIAL IS

NEW POSTERIOR FOR THETA 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 6.6670001E-02 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 0.1333300 IS 1.4998815E-31
NEW POSTERIOR FOR THETA 0.2000000 IS 4.4839803E-18
NEW POSTERIOR FOR THETA 0.2666700 IS 3.8458639E-10
NEW POSTERIOR FOR THETA 0.3333300 IS 1.7367700E-05
NEW POSTERIOR FOR THETA 0.4000000 IS 0.1016216
NEW POSTERIOR FOR THETA 0.4666700 IS 0.7994599
NEW POSTERIOR FOR THETA 0.5333300 IS 9.8873891E-02
NEW POSTERIOR FOR THETA 0.6000000 IS 2.7164637E-05
NEW POSTERIOR FOR THETA 0.6666700 IS 5.7490360E-11
NEW POSTERIOR FOR THETA 0.7333300 IS 3.0235109E-20
NEW POSTERIOR FOR THETA 0.8000000 IS 6.3720487E-32
NEW POSTERIOR FOR THETA 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 6.6670001E-02 IS 2.4184373E-20
NEW POSTERIOR FOR THETA 0.1333300 IS 2.9283279E-07
NEW POSTERIOR FOR THETA 0.2000000 IS 3.2180324E-02
NEW POSTERIOR FOR THETA 0.2666700 IS 0.8541485
NEW POSTERIOR FOR THETA 0.3333300 IS 0.1134307
NEW POSTERIOR FOR THETA 0.4000000 IS 2.4014065E-04
NEW POSTERIOR FOR THETA 0.4666700 IS 1.1883668E-08
NEW POSTERIOR FOR THETA 0.5333300 IS 1.2658284E-14
NEW POSTERIOR FOR THETA 0.6000000 IS 1.7500915E-22
NEW POSTERIOR FOR THETA 0.6666700 IS 1.1167656E-32
NEW POSTERIOR FOR THETA 0.7333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA 1.000000 IS 0.0000000E+00
****

```
THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS
------------------------------------------------
NEW POSTERIOR FOR THETA   0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA   6.6670001E-02  IS  0.8905320
NEW POSTERIOR FOR THETA   0.1333300      IS  0.1094512
NEW POSTERIOR FOR THETA   0.2000000      IS  1.6742653E-05
NEW POSTERIOR FOR THETA   0.2666700      IS  6.4999436E-11
NEW POSTERIOR FOR THETA   0.3333300      IS  1.3426987E-17
NEW POSTERIOR FOR THETA   0.4000000      IS  1.6069862E-25
NEW POSTERIOR FOR THETA   0.4666700      IS  8.7113039E-35
NEW POSTERIOR FOR THETA   0.5333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.6000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA    1.000000      IS  0.0000000E+00
**********************************************************

THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS
------------------------------------------------
NEW POSTERIOR FOR THETA   0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA   6.6670001E-02  IS  1.2333999E-06
NEW POSTERIOR FOR THETA   0.1333300      IS  3.2370355E-02
NEW POSTERIOR FOR THETA   0.2000000      IS  0.9255465
NEW POSTERIOR FOR THETA   0.2666700      IS  4.2058226E-02
NEW POSTERIOR FOR THETA   0.3333300      IS  2.4896568E-05
NEW POSTERIOR FOR THETA   0.4000000      IS  3.9609982E-10
NEW POSTERIOR FOR THETA   0.4666700      IS  1.9253207E-16
NEW POSTERIOR FOR THETA   0.5333300      IS  2.1897684E-24
NEW POSTERIOR FOR THETA   0.6000000      IS  2.9736999E-34
NEW POSTERIOR FOR THETA   0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA   0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA    1.000000      IS  0.0000000E+00
**********************************************************
```

AD-A185 249 A METHODOLOGY FOR DETERMINING THE INTENT OF A LIMITED NUCLEAR ATTACK(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING 3/3

UNCLASSIFIED R L BIVINS MAY 87 AFIT/GSI/ENS/87J-2 F/G 15/6.4 NL

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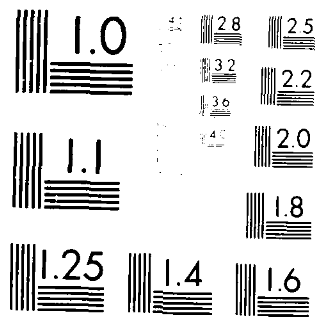

MICROCOPY RESOLUTION TEST CHART

MOE IS: 0.866667
AT 360.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 6
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 1
CLASS 4, COMMAND & CONTROL,COMM: 4

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.1333300 IS 9.3857267E-38
NEW POSTERIOR FOR THETA = 0.2000000 IS 4.3042319E-21
NEW POSTERIOR FOR THETA = 0.2666700 IS 2.3343194E-11
NEW POSTERIOR FOR THETA = 0.3333300 IS 9.9269673E-06
NEW POSTERIOR FOR THETA = 0.4000000 IS 0.1387112
NEW POSTERIOR FOR THETA = 0.4666700 IS 0.8341351
NEW POSTERIOR FOR THETA = 0.5333300 IS 2.7143082E-02
NEW POSTERIOR FOR THETA = 0.6000000 IS 6.4300713E-07
NEW POSTERIOR FOR THETA = 0.6666700 IS 3.2085046E-14
NEW POSTERIOR FOR THETA = 0.7333300 IS 7.4203554E-26
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 4.7382295E-26
NEW POSTERIOR FOR THETA = 0.1333300 IS 3.1035223E-09
NEW POSTERIOR FOR THETA = 0.2000000 IS 1.0757698E-02
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.9009884
NEW POSTERIOR FOR THETA = 0.3333300 IS 8.8209219E-02
NEW POSTERIOR FOR THETA = 0.4000000 IS 4.4641467E-05
NEW POSTERIOR FOR THETA = 0.4666700 IS 1.9173273E-10
NEW POSTERIOR FOR THETA = 0.5333300 IS 6.3457082E-18
NEW POSTERIOR FOR THETA = 0.6000000 IS 8.5893317E-28
NEW POSTERIOR FOR THETA = 0.6666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.7333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS

```
NEW POSTERIOR FOR THETA = 0.0000000E+00  IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02  IS 0.9374088
NEW POSTERIOR FOR THETA = 0.1333300      IS 6.2590316E-02
NEW POSTERIOR FOR THETA = 0.2000000      IS 8.9045921E-07
NEW POSTERIOR FOR THETA = 0.2666700      IS 1.2160173E-13
NEW POSTERIOR FOR THETA = 0.3333300      IS 4.0564041E-22
NEW POSTERIOR FOR THETA = 0.4000000      IS 3.6755363E-32
NEW POSTERIOR FOR THETA = 0.4666700      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.5333300      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.6000000      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.6666700      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.7333300      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300      IS 0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000      IS 0.0000000E+00
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THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS

```
NEW POSTERIOR FOR THETA = 0.0000000E+00  IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02  IS 1.1269402E-12
NEW POSTERIOR FOR THETA = 0.1333300      IS 7.4367411E-03
NEW POSTERIOR FOR THETA = 0.2000000      IS 0.9617536
NEW POSTERIOR FOR THETA = 0.2666700      IS 3.0805947E-02
NEW POSTERIOR FOR THETA = 0.3333300      IS 3.7615407E-06
NEW POSTERIOR FOR THETA = 0.4000000      IS 4.5262531E-12
NEW POSTERIOR FOR THETA = 0.4666700      IS 6.4341352E-20
NEW POSTERIOR FOR THETA = 0.5333300      IS 7.8136791E-30
NEW POSTERIOR FOR THETA = 0.6000000      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.6666700      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.7333300      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700      IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300      IS 0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000      IS 0.0000000E+00
**************************************************
```

Appendix L Perfect Radar Information Posterior Probabilities

MOE IS: 0.866667

AT 900.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 6
CLASS 2, OTHER MILITARY: 3
CLASS 3, STRATEGIC MILITARY: 2
CLASS 4, COMMAND & CONTROL,COMM: 4

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 4.3975006E-06
NEW POSTERIOR FOR THETA = 0.1333300 IS 1.4439678E-04
NEW POSTERIOR FOR THETA = 0.2000000 IS 8.0038002E-04
NEW POSTERIOR FOR THETA = 0.2666700 IS 2.0551626E-03
NEW POSTERIOR FOR THETA = 0.3333300 IS 3.3246884E-03
NEW POSTERIOR FOR THETA = 0.4000000 IS 0.1068378
NEW POSTERIOR FOR THETA = 0.4666700 IS 0.2799938
NEW POSTERIOR FOR THETA = 0.5333300 IS 0.5002171
NEW POSTERIOR FOR THETA = 0.6000000 IS 9.4966874E-02
NEW POSTERIOR FOR THETA = 0.6666700 IS 1.1543527E-02
NEW POSTERIOR FOR THETA = 0.7333300 IS 9.8825774E-05
NEW POSTERIOR FOR THETA = 0.8000000 IS 1.2505929E-05
NEW POSTERIOR FOR THETA = 0.8666700 IS 5.2575018E-07
NEW POSTERIOR FOR THETA = 0.9333300 IS 1.6028454E-09
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 6.2777497E-02
NEW POSTERIOR FOR THETA = 0.1333300 IS 0.2063568
NEW POSTERIOR FOR THETA = 0.2000000 IS 0.2665385
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.2223851
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.1384026
NEW POSTERIOR FOR THETA = 0.4000000 IS 6.7543700E-02
NEW POSTERIOR FOR THETA = 0.4666700 IS 2.6095873E-02
NEW POSTERIOR FOR THETA = 0.5333300 IS 7.8468667E-03
NEW POSTERIOR FOR THETA = 0.6000000 IS 1.7569655E-03
NEW POSTERIOR FOR THETA = 0.6666700 IS 2.7028067E-04
NEW POSTERIOR FOR THETA = 0.7333300 IS 2.4727377E-05
NEW POSTERIOR FOR THETA = 0.8000000 IS 1.0167624E-06
NEW POSTERIOR FOR THETA = 0.8666700 IS 9.9605977E-09
NEW POSTERIOR FOR THETA = 0.9333300 IS 3.0399116E-12
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

```
THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS
-------------------------------------------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  0.2037163
NEW POSTERIOR FOR THETA =  0.1333300      IS  0.3109293
NEW POSTERIOR FOR THETA =  0.2000000      IS  0.2471365
NEW POSTERIOR FOR THETA =  0.2666700      IS  0.1417581
NEW POSTERIOR FOR THETA =  0.3333300      IS  6.4164929E-02
NEW POSTERIOR FOR THETA =  0.4000000      IS  2.3485141E-02
NEW POSTERIOR FOR THETA =  0.4666700      IS  6.9131334E-03
NEW POSTERIOR FOR THETA =  0.5333300      IS  1.5915751E-03
NEW POSTERIOR FOR THETA =  0.6000000      IS  2.7151196E-04
NEW POSTERIOR FOR THETA =  0.6666700      IS  3.1325319E-05
NEW POSTERIOR FOR THETA =  0.7333300      IS  2.0843454E-06
NEW POSTERIOR FOR THETA =  0.8000000      IS  5.8921863E-08
NEW POSTERIOR FOR THETA =  0.8666700      IS  3.5520284E-10
NEW POSTERIOR FOR THETA =  0.9333300      IS  5.0335360E-14
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
**************************************************


THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS
-------------------------------------------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  1.3465963E-02
NEW POSTERIOR FOR THETA =  0.1333300      IS  9.5330343E-02
NEW POSTERIOR FOR THETA =  0.2000000      IS  0.2000959
NEW POSTERIOR FOR THETA =  0.2666700      IS  0.2428392
NEW POSTERIOR FOR THETA =  0.3333300      IS  0.2078002
NEW POSTERIOR FOR THETA =  0.4000000      IS  0.1352172
NEW POSTERIOR FOR THETA =  0.4666700      IS  6.8568379E-02
NEW POSTERIOR FOR THETA =  0.5333300      IS  2.6929030E-02
NEW POSTERIOR FOR THETA =  0.6000000      IS  7.9139406E-03
NEW POSTERIOR FOR THETA =  0.6666700      IS  1.6232665E-03
NEW POSTERIOR FOR THETA    0.7333300      IS  2.0419332E-04
NEW POSTERIOR FOR THETA =  0.8000000      IS  1.2212872E-05
NEW POSTERIOR FOR THETA =  0.8666700      IS  1.9442382E-07
NEW POSTERIOR FOR THETA =  0.9333300      IS  1.2779210E-10
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
**************************************************
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MOE IS: 0.933333

AT 600.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 5
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 2
CLASS 4, COMMAND & CONTROL,COMM: 4

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 6.6242504E-25
NEW POSTERIOR FOR THETA = 0.1333300 IS 1.4764365E-11
NEW POSTERIOR FOR THETA = 0.2000000 IS 1.7445456E-05
NEW POSTERIOR FOR THETA = 0.2666700 IS 1.3163893E-02
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.1082553
NEW POSTERIOR FOR THETA = 0.4000000 IS 0.8408837
NEW POSTERIOR FOR THETA = 0.4666700 IS 3.7595041E-02
NEW POSTERIOR FOR THETA = 0.5333300 IS 8.4689862E-05
NEW POSTERIOR FOR THETA = 0.6000000 IS 1.1722412E-09
NEW POSTERIOR FOR THETA = 0.6666700 IS 3.3358529E-16
NEW POSTERIOR FOR THETA = 0.7333300 IS 6.8413715E-26
NEW POSTERIOR FOR THETA = 0.8000000 IS 2.1502974E-37
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 5.9472148E-14
NEW POSTERIOR FOR THETA = 0.1333300 IS 6.1810992E-05
NEW POSTERIOR FOR THETA = 0.2000000 IS 0.1325185
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.7663514
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.1004011
NEW POSTERIOR FOR THETA = 0.4000000 IS 6.6686742E-04
NEW POSTERIOR FOR THETA = 0.4666700 IS 2.8969836E-07
NEW POSTERIOR FOR THETA = 0.5333300 IS 7.6039418E-12
NEW POSTERIOR FOR THETA = 0.6000000 IS 8.1813705E-18
NEW POSTERIOR FOR THETA = 0.6666700 IS 1.6590083E-25
NEW POSTERIOR FOR THETA = 0.7333300 IS 1.5056659E-35
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

```
THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS
----------------------------------------------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  8.7637827E-03
NEW POSTERIOR FOR THETA =  0.1333300      IS  0.9176707
NEW POSTERIOR FOR THETA =  0.2000000      IS  7.3403068E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  1.6234427E-04
NEW POSTERIOR FOR THETA =  0.3333300      IS  2.6526727E-08
NEW POSTERIOR FOR THETA =  0.4000000      IS  4.1892228E-13
NEW POSTERIOR FOR THETA =  0.4666700      IS  6.0232821E-19
NEW POSTERIOR FOR THETA =  0.5333300      IS  5.8010545E-26
NEW POSTERIOR FOR THETA =  0.6000000      IS  2.0657936E-34
NEW POSTERIOR FOR THETA =  0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
**************************************************


THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS
----------------------------------------------
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  1.1720508E-14
NEW POSTERIOR FOR THETA =  0.1333300      IS  2.6234788E-05
NEW POSTERIOR FOR THETA =  0.2000000      IS  9.1401726E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  0.7688479
NEW POSTERIOR FOR THETA =  0.3333300      IS  0.1384969
NEW POSTERIOR FOR THETA =  0.4000000      IS  1.2265519E-03
NEW POSTERIOR FOR THETA =  0.4666700      IS  6.9935487E-07
NEW POSTERIOR FOR THETA =  0.5333300      IS  2.3975221E-11
NEW POSTERIOR FOR THETA =  0.6000000      IS  3.3857512E-17
NEW POSTERIOR FOR THETA =  0.6666700      IS  9.1542526E-25
NEW POSTERIOR FOR THETA =  0.7333300      IS  1.1423299E-34
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
**************************************************
```

MOE IS: 0.9333333

AT 480.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 5
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 2
CLASS 4, COMMAND & CONTROL,COMM: 4

THE NEW DISTRIBUTION FOR CITY INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 8.1681877E-33
NEW POSTERIOR FOR THETA = 0.1333300 IS 9.8377176E-15
NEW POSTERIOR FOR THETA = 0.2000000 IS 1.5734520E-06
NEW POSTERIOR FOR THETA = 0.2666700 IS 1.1529653E-02
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.1816959
NEW POSTERIOR FOR THETA = 0.4000000 IS 0.7997549
NEW POSTERIOR FOR THETA = 0.4666700 IS 7.0168171E-03
NEW POSTERIOR FOR THETA = 0.5333300 IS 1.0942516E-06
NEW POSTERIOR FOR THETA = 0.6000000 IS 3.3528315E-13
NEW POSTERIOR FOR THETA = 0.6666700 IS 5.3379059E-22
NEW POSTERIOR FOR THETA = 0.7333300 IS 9.7964563E-35
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 6.3803749E-19
NEW POSTERIOR FOR THETA = 0.1333300 IS 1.6656096E-06
NEW POSTERIOR FOR THETA = 0.2000000 IS 6.9312558E-02
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.8695322
NEW POSTERIOR FOR THETA = 0.3333300 IS 6.1080877E-02
NEW POSTERIOR FOR THETA = 0.4000000 IS 7.2736104E-05
NEW POSTERIOR FOR THETA = 0.4666700 IS 2.0894135E-09
NEW POSTERIOR FOR THETA = 0.5333300 IS 1.3046814E-15
NEW POSTERIOR FOR THETA = 0.6000000 IS 1.0470802E-23
NEW POSTERIOR FOR THETA = 0.6666700 IS 3.7582935E-34
NEW POSTERIOR FOR THETA = 0.7333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS

```
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  1.7024318E-03
NEW POSTERIOR FOR THETA =  0.1333300      IS  0.9674060
NEW POSTERIOR FOR THETA =  0.2000000      IS  3.0884240E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  7.3944234E-06
NEW POSTERIOR FOR THETA =  0.3333300      IS  5.0716566E-11
NEW POSTERIOR FOR THETA =  0.4000000      IS  1.4374123E-17
NEW POSTERIOR FOR THETA =  0.4666700      IS  1.5517015E-25
NEW POSTERIOR FOR THETA =  0.5333300      IS  4.1984660E-35
NEW POSTERIOR FOR THETA =  0.6000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
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THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS

```
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  1.2517046E-19
NEW POSTERIOR FOR THETA =  0.1333300      IS  7.0373289E-07
NEW POSTERIOR FOR THETA =  0.2000000      IS  4.7589660E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  0.8684021
NEW POSTERIOR FOR THETA =  0.3333300      IS  8.3874375E-02
NEW POSTERIOR FOR THETA =  0.4000000      IS  1.3317396E-04
NEW POSTERIOR FOR THETA =  0.4666700      IS  5.0211000E-09
NEW POSTERIOR FOR THETA =  0.5333300      IS  4.0949740E-15
NEW POSTERIOR FOR THETA =  0.6000000      IS  4.3135189E-23
NEW POSTERIOR FOR THETA =  0.6666700      IS  2.0643710E-33
NEW POSTERIOR FOR THETA =  0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =   1.000000      IS  0.0000000E+00
**************************************************
```

MOE IS: 0.9333333

AT 360.0000 SECONDS BEFORE IMPACT
THERE ARE THE FOLLOWING NUMBERS OF WARHEADS TARGETED
FOR EACH RESPECTIVE CLASS

CLASS 1, CITY/INDUSTRIAL: 5
CLASS 2, OTHER MILITARY: 4
CLASS 3, STRATEGIC MILITARY: 2
CLASS 4, COMMAND & CONTROL,COMM: 4

THE NEW DISTRIBUTION FOR CITY/INDUSTRIAL IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.1333300 IS 6.0863424E-18
NEW POSTERIOR FOR THETA = 0.2000000 IS 1.3176708E-07
NEW POSTERIOR FOR THETA = 0.2666700 IS 9.3762791E-03
NEW POSTERIOR FOR THETA = 0.3333300 IS 0.2831546
NEW POSTERIOR FOR THETA = 0.4000000 IS 0.7062530
NEW POSTERIOR FOR THETA = 0.4666700 IS 1.2159960E-03
NEW POSTERIOR FOR THETA = 0.5333300 IS 1.3127601E-08
NEW POSTERIOR FOR THETA = 0.6000000 IS 8.9040739E-17
NEW POSTERIOR FOR THETA = 0.6666700 IS 7.9308057E-28
NEW POSTERIOR FOR THETA = 0.7333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR OTHER MILITARY IS

NEW POSTERIOR FOR THETA = 0.0000000E+00 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 6.6670001E-02 IS 6.4574679E-24
NEW POSTERIOR FOR THETA = 0.1333300 IS 4.2341298E-08
NEW POSTERIOR FOR THETA = 0.2000000 IS 3.4200374E-02
NEW POSTERIOR FOR THETA = 0.2666700 IS 0.9307367
NEW POSTERIOR FOR THETA = 0.3333300 IS 3.5055429E-02
NEW POSTERIOR FOR THETA = 0.4000000 IS 7.4841787E-06
NEW POSTERIOR FOR THETA = 0.4666700 IS 1.4216293E-11
NEW POSTERIOR FOR THETA = 0.5333300 IS 2.1118044E-19
NEW POSTERIOR FOR THETA = 0.6000000 IS 1.2642043E-29
NEW POSTERIOR FOR THETA = 0.6666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.7333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8000000 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.8666700 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 0.9333300 IS 0.0000000E+00
NEW POSTERIOR FOR THETA = 1.000000 IS 0.0000000E+00
****

THE NEW DISTRIBUTION FOR STRATEGIC MILITARY IS

```
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  3.2009522E-04
NEW POSTERIOR FOR THETA =  0.1333300      IS  0.9871022
NEW POSTERIOR FOR THETA =  0.2000000      IS  1.2577406E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  3.2598911E-07
NEW POSTERIOR FOR THETA =  0.3333300      IS  9.3852843E-14
NEW POSTERIOR FOR THETA =  0.4000000      IS  4.7737611E-22
NEW POSTERIOR FOR THETA =  0.4666700      IS  3.8691402E-32
NEW POSTERIOR FOR THETA =  0.5333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.6000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000       IS  0.0000000E+00
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THE NEW DISTRIBUITON FOR COMMAND AND CONTROL IS

```
NEW POSTERIOR FOR THETA =  0.0000000E+00  IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  6.6670001E-02  IS  1.2653616E-24
NEW POSTERIOR FOR THETA =  0.1333300      IS  1.7868803E-08
NEW POSTERIOR FOR THETA =  0.2000000      IS  2.3454614E-02
NEW POSTERIOR FOR THETA =  0.2666700      IS  0.9284504
NEW POSTERIOR FOR THETA =  0.3333300      IS  4.8081279E-02
NEW POSTERIOR FOR THETA =  0.4000000      IS  1.3687056E-05
NEW POSTERIOR FOR THETA =  0.4666700      IS  3.4123811E-11
NEW POSTERIOR FOR THETA =  0.5333300      IS  6.6205970E-19
NEW POSTERIOR FOR THETA =  0.6000000      IS  5.2019446E-29
NEW POSTERIOR FOR THETA =  0.6666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.7333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8000000      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.8666700      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  0.9333300      IS  0.0000000E+00
NEW POSTERIOR FOR THETA =  1.000000       IS  0.0000000E+00
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Appendix M Radar Sensitivity

Time to Impact (Seconds)	One	Two	Three	Four	Five	Six
900	0.6000	0.6000	0.6000	0.6000	0.7333	0.9333
870	0.4667	0.4667	0.6000	0.6667	0.8000	1.0000
840	0.6000	0.6000	0.4667	0.8000	0.8000	1.0000
810	0.4667	0.4667	0.4667	0.6667	0.8000	1.0000
780	0.5334	0.5334	0.6000	0.8667	0.8667	1.0000
750	0.6000	0.4667	0.5334	0.7333	0.8667	1.0000
720	0.6667	0.7333	0.8000	0.8000	0.8667	1.0000
690	0.6000	0.6000	0.8000	0.8667	0.8000	1.0000
660	0.7333	0.6667	0.8000	0.8000	0.8000	1.0000
630	0.5334	0.6000	0.6667	0.8000	0.8667	1.0000
600	0.6000	0.6000	0.7333	0.8000	0.8667	1.0000
570	0.7333	0.7333	0.7333	0.8000	0.8667	1.0000
540	0.7333	0.7333	0.6667	0.7333	0.9333	1.0000
510	0.7333	0.8000	0.8000	0.8667	0.9333	1.0000
480	0.6667	0.6667	0.7333	0.8000	0.8667	1.0000
450	0.7333	0.7333	0.8667	0.8667	0.8667	1.0000
420	0.7333	0.7333	0.8667	0.8667	0.8667	1.0000
390	0.6667	0.6667	0.8000	0.8667	0.8667	1.0000
360	0.7333	0.8000	0.8000	0.8667	0.8667	1.0000

Appendix N CEP Simulation

Time to Impact	900 CEP	600 CEP	300 CEP	0 CEP
900	0.6000	0.6000	0.6000	0.5333
870	0.8000	0.8000	0.6667	0.7333
840	0.8667	0.8667	0.8000	0.7333
810	0.8000	0.8000	0.6667	0.8667
780	0.8667	0.8000	0.8667	0.8000
750	0.7333	0.7333	0.7333	0.7333
720	0.8000	0.8000	0.8000	0.8000
690	0.7333	0.6667	0.8667	0.6667
660	0.8667	0.8000	0.8000	0.8000
630	0.8000	0.7333	0.8000	0.8000
600	0.8667	0.8000	0.8000	0.8000
570	0.8000	0.8000	0.8000	0.8000
540	0.7333	0.7333	0.7333	0.7333
510	0.8667	0.8667	0.8667	0.8667
480	0.9333	0.9333	0.8000	0.9333
450	0.8667	0.8667	0.8667	0.9333
420	0.8000	0.8000	0.8667	0.8000
390	0.7333	0.7333	0.8667	0.7333
360	0.9333	0.9333	0.8667	0.8667

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VITA

Captain Robert L. Bivins was born on 7 October 1954 in Owensboro, Kentucky. He graduated from Daviess County High School in Owensboro in 1972. He entered the United States Air Force Academy and graduated with a Bachelor of Science degree in Chemistry in 1976. As a newly commissioned officer in the United States Air Force, he began his military career as a Titan II Deputy Missile Combat Crew Commander with the 390th Strategic Missile Wing at Davis-Monthan Air Force Base Arizona. He became an instructor Deputy Missile Combat Crew Commander within a year and then upgraded to a commander's position a year and a half later. He returned to the instructor shop as a Missile Combat Crew Commander where he remained until 1981. His second assignment was as an instructor at the Air Force Academy Preparatory School. He spent four years there as an instructor and was a Department Head for the last two of those years. In August of 1985 he entered the Graduate of Strategic and Tactical Sciences program at the Air Force Institute of Technology, Wright-Patterson AFB Ohio. His graduate degrees include a Masters of Arts degree in Public Administration from the University of Northern Colorado and a Masters of Sciences degree in Systems Management from the University of Southern California. Captain Bivins is a member of Tau Beta Pi and Omega Rho.

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at AFIT [37]. The results from these algorithms have been validated during two quarters of nuclear survivability courses from 31 March 1986 to 11 July 1986. An inspection of the data in Appendix D shows the results to be reasonable.

As the range increases between the target and the impact point, the P_k generally decreases. This inverse relationship generally exists because the nuclear effects diminish as the reciprocal of $Range^2$. However, this relationship is not an absolute because of a phenomenon associated with the thermal effects. There is a time lag involved with thermal effects. The maximum thermal radiation value does not occur at the same range as the maximum blast overpressure value [38]. This explains the apparent anomalies in the data when the P_k does not always decrease with the range. This anomaly is small and insignificant in determining the overall probability of kill.

Another proof of model validity is a comparison of the calculated overpressure values with predicted values. The model results were compared with figures 3.73a, b, and c of *The Effects of Nuclear Weapons*. There was good agreement between calculated results from the model and predicted results from the nuclear effects tables [18]. The model is accepted as providing valid data.

Overview of Using Model Results to Determine Intent

The volume of data generated by the three previously discussed models are of little value without a methodology to take that data and from it determine intent. Chapter IV will discuss the development of the methodology to combine the calculated damage with intent determination. The methodology determines how the estimates of intent are changing over time as the data becomes more certain.

Figure 3.3 shows each of the data files which are used and generated by the three models previously discussed. As is shown in the figure, the data generated by each model is used to drive the next model in sequence until finally a data file is produced containing

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